

Chapter 8

BMP OVERVIEW AND SELECTION CRITERIA

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8.0. INTRODUCTION

The application of Best Management Practices (BMPs) to stormwater management has broadened in the past ten years. With EPA's implementation of various kinds of federal stormwater permits for localities with Municipal Separate Storm Sewer Systems (MS4s) and for building construction-related stormwater runoff control (both administered in Virginia through delegation to the DEQ), a broad array of practices has been identified as appropriate for managing stormwater. It is important for stormwater managers to understand the full context of these programs and related stormwater impacts, to see how they fit together and, thus, to understand what kinds of practices to employ for the various purposes. This chapter provides an overview of the various kinds of BMPs that must be employed, but it focuses especially on the "post-construction" practices that must be built during site development with the intent of managing site runoff perpetually after construction is completed. Then the chapter provides useful guidance regarding how to make the best selection of BMPs for a development project.

Flow-Related Issues

Section 4.1.6 of Chapter 4 of this Handbook discusses the hydrologic changes that occur in response to land development and added impervious cover. Maintaining or at least mimicking the pre-development hydrologic conditions is recommended in all cases, but especially for receiving water bodies that are highly or moderately susceptible to stormwater impacts. The relationship between any storm event, no matter how small or how large, and runoff volumes must be thoroughly understood. BMPs that address the full range of hydrologic conditions should be employed to minimize impacts.

In parts of Virginia with particularly cold winter climates, snow melt events pose a significant problem. A large volume of water occurs at the end of the winter when many impediments, such as frozen ground for infiltration basins or frozen permanent pools and clogged outlets for pond systems, may be at their worst. Thus the effectiveness of these BMPs is often compromised during such critical runoff events (CWP, 1997).

Pollutants of Concern

Section 4.5.4 of Chapter 4 of this Handbook discusses the water quality impacts that are common on urban and suburban (or developing) land. That section identifies the most prominent pollutants (see **Table 4.7**), indicates where on the land surface they are most likely to be generated (see **Figure 4.35**), and identifies the treatment mechanisms that are likely to be successful in removing or reducing each type of pollutant.

With careful site planning, developers and municipalities can reduce the amount of impervious area created by pavement and roofs, thus reducing the volume of stormwater runoff and associated pollutants requiring control. By employing BMPs that further reduce runoff volume, site designers can further reduce the negative impacts of development and perhaps avoid the need for some of the traditional stormwater management infrastructure resulting from the use of more traditional BMPs.

8.1. CATEGORIES OF BMPs AND THE MOST EFFECTIVE ORDER OF IMPLEMENTING THEM

Remember that the goal of pollution prevention is to prevent contact of rainfall or stormwater runoff with pollutants, thus reducing pollutant loads to water bodies while maintaining as much of the watershed's natural (predevelopment) hydrology as possible. Thus, *stormwater control measures (BMPs) are most effective from the perspective of both efficiency and cost when stormwater management is considered and incorporated in the early planning stages of a community, watershed or development project.*

As noted in **Chapter 5**, many, if not most, development sites will need to employ multiple practices in order to satisfy the nutrient reduction requirements in the Regulations and adequately manage the stormwater runoff. Under the treatment train approach, stormwater management begins at the site level with simple methods that minimize the amount of runoff that occurs from a site and methods that prevent pollution from accumulating on the land surface and becoming available for transport in runoff from the site ("source controls" or non-structural BMPs or Better/Environmental Site Design).

The following is a brief description of each of the categories of practices listed in **Table 5.1** (in **Chapter 5**), which reflect the correct order of BMP implementation. Following these descriptions, there will be more specific descriptions of the post-construction BMPs that are more the focus of this Handbook.

8.1.1. Product Substitution

Product substitution refers to one of the classic pollution prevention approaches of reducing the availability of pollutants for future wash-off into stormwater runoff. The most notable example is the introduction of unleaded gasoline, which resulted in an order-of-magnitude reduction of lead levels in stormwater runoff in a decade (Pitt et al., 2004a, b). Similar reductions are expected with the phase-out of methyl tert-butyl ether (MTBE) additives in gasoline. Other examples of product substitution are the ban on coal-tar sealants during parking lot renovation that has reduced PAH runoff (Van Metre et al., 2006), phosphorus-free fertilizers that have measurably reduced phosphorus runoff (Barten and Johnson, 2007), the painting of galvanized metal surfaces, and alternative rooftop surfaces (Clark et al., 2005). Given the importance of coal power plant emissions in the atmospheric deposition of nitrogen and mercury, it is possible that future emissions reductions for such plants may result in lower stormwater runoff concentrations for these two pollutants.

8.1.2. Watershed Land-Use Planning

Communities can address stormwater problems by making land-use decisions that change the location or quantity of impervious cover created by new development. This can be accomplished through zoning, watershed plans, comprehensive land-use plans, or Smart Growth incentives.

The unit process that is managed is the amount of impervious cover, which is strongly related to various residential and commercial zoning categories (Capiella and Brown, 2000). Numerous

techniques exist to forecast future watershed impervious cover and its probable impact on the quality of aquatic resources (see discussion of the Impervious Cover Model in **Appendix 5-A (Chapter 5)**; (CWP, 1998a; MD DNR, 2005). Using these techniques and simple or complex simulation models, planners can estimate stormwater flows and pollutant loads through the watershed planning process and alter the location or intensity of development to reduce them.

The level of control that can be achieved by watershed and land-use planning is theoretically high, but relatively few communities have aggressively exercised it. The most common application of down-zoning has been applied to watersheds that drain to drinking water reservoirs (Kitchell, 2002). The strength of this practice is that it has the potential to directly address the underlying causes of the stormwater problem rather than just treating its numerous symptoms. The weakness is that local decisions on zoning and Smart Growth are reversible and often driven by other community concerns and priorities, such as economic development, adequate infrastructure, and transportation. In addition, powerful consumer and market forces often have promoted low-density sprawl development. Communities that use watershed-based zoning often require a compelling local environmental goal, since state and federal regulatory authorities have traditionally been extremely reluctant to interfere with the local land-use and zoning powers.

8.1.3. Conservation of Natural Areas

Natural area conservation protects natural features and environmental resources that help maintain the predevelopment hydrology of a site by reducing runoff, promoting infiltration, and preventing soil erosion. Natural areas can be legally protected by a permanent conservation easement prescribing allowable uses and activities on the parcel and preventing future development. Examples include any areas of undisturbed vegetation preserved at the development site, including forests, wetlands, native grasslands, floodplains and riparian areas, zero-order stream channels, springs and seeps, ridge tops or steep slopes, and stream, wetland, or shoreline buffers. In general, conservation should maximize contiguous area and avoid habitat fragmentation.

While natural areas are conserved at many development sites, most of these requirements are prompted by other local, state, and federal habitat protections, and are not explicitly designed or intended to provide runoff reduction and stormwater treatment. To date, there are virtually no data to quantify the runoff reduction and/or pollutant removal capability of specific types of natural area conservation, or the ability to explicitly link them to site design.

8.1.4. Impervious Cover Reduction

A variety of practices, some of which fall under the broader term “better site design (BSD)” or “environmental site design (ESD),” can be used to minimize the creation of new impervious cover and disconnect or make more permeable the hard surfaces that are needed (Nichols et al., 1997; Richman, 1997; CWP, 1998a). The following is a list of some common impervious cover reduction practices for both residential and commercial areas:

Elements of Environmental Site Design: Single-Family Residential Sites

- Reducing the residential street width
- Reducing the street right-of-way (ROW) width
- Using swales and other BMPs that can be located within the ROW
- Reducing the cul-de-sac radius
- Installing vegetation and, ideally, a bioretention BMP on the island in the center of the cul-de-sac
- Alternative turn-around options, such as hammerheads, are acceptable if they reduce impervious cover
- Narrow sidewalks on one side of the street only (or move pedestrian pathways away from the street entirely)
- Disconnect rooftops from the storm-drain systems
- Minimize driveway length and width or share driveways, and use permeable surfaces
- Allow for cluster or open-space designs (e.g., zero lot line) that reduce lot size or setbacks in exchange for conservation of natural areas
- Permeable pavement in parking areas, driveways, sidewalks, walkways, and patios

Elements of Environmental Site Design: Multi-Family Residential and Commercial Sites

- Design buildings and parking to have multiple levels
- Store rooftop runoff in green roofs, foundation planters, bioretention areas, or cisterns
- Reduce parking lot size by reducing parking demand ratios and stall dimensions
- Use landscaping areas, tree pits, and planters for stormwater treatment
- Use permeable pavement for parking areas, plazas, and courtyards

CWP (1998a) recommends minimum or maximum geometric dimensions for subdivisions, individual lots, streets, sidewalks, cul-de-sacs, and parking lots that minimize the generation of needless impervious cover, based on a national roundtable of fire safety, planning, transportation and zoning experts. Specific changes in local development codes can be made using these criteria, but it is often important to engage as many municipal agencies that are involved in development as possible in order to gain consensus on code changes.

At the present time there is little research available to define the runoff reduction benefits of these practices. However, modeling studies consistently show a 10-45 percent reduction in runoff compared to conventional development (CWP, 1998b, c, 2002). Several monitoring studies have documented a major reduction in stormwater runoff from development sites that employ various forms of impervious cover reduction and LID in the United States and Australia (Coombes et al., 2000; Philips et al., 2003; Cheng et al., 2005) compared to those that do not.

Unfortunately, environmental site design has been slowly adopted by local planners, developers, designers, and public works officials. For example, although the Seattle Green Street project pictured in **Figure 5.2 (Chapter 5)** has been very successful in terms of controlling stormwater, the environmental site design principles used have not been widely adopted in the Seattle area. Existing local development codes may discourage or even prohibit the application of

environmental site design practices, and many engineers and plan reviewers are hesitant to embrace them. Impervious cover reduction must be incorporated at the earliest stage of site layout and design to be effective, but outdated development codes in many communities can greatly restrict the scope of impervious cover reduction. Finally, the performance and longevity of impervious cover reduction is dependent on the infiltration capability of local soils, the intensity of development, and the future management actions of landowners.

8.1.5. Earthwork Minimization

This source control measure seeks to limit the degree of clearing and grading on a development site in order to prevent soil compaction, conserve soil structure, prevent erosion from steep slopes, and protect zero-order streams. This concept can be applied in two ways by (1) minimizing the total site area that must be cleared and graded to complete the project; and (2) minimizing the site area that must be cleared and graded at any one time by completing large projects in phases, stabilizing one phase as the next phase is being cleared. This is accomplished by (1) identifying key soils, drainage features, and slopes to protect, and then (2) establishing limits of disturbance beyond which construction equipment is excluded. This element is an important but often under-utilized component of local erosion and sediment control plans.

Numerous researchers have documented the impact of mass grading, clearing, and the passage of construction equipment on the compaction of soils, as measured by increases in bulk density, declines in soil permeability, and increases in the runoff coefficient (Lichter and Lindsey, 1994; Legg et al., 1996; Schueler, 2001a, b; Gregory et al., 2006). Another goal of earthwork minimization is to protect zero-order streams, which are channels with defined banks that emanate from a hollow or ravine with convergent contour lines (Gomi et al., 2002). They represent the uppermost definable channels that possess temporary or intermittent flow. Functioning zero-order channels provide major watershed functions, including groundwater recharge and discharge (Schollen et al., 2006; Winter, 2007), important nutrient storage and transformation functions (Bernot and Dodds, 2005; Groffman et al., 2005), storage and retention of eroded hill slope sediments (Meyers, 2003), and delivery of leaf inputs and large woody debris. Compared to high-order network streams, zero-order streams are disproportionately disturbed by mass grading, enclosure, or channelization (Gomi et al., 2002; Meyers, 2003).

The practice of earthwork minimization is not widely applied across Virginia. This is partly due to the limited performance data available to quantify its benefits, and the absence of local or national design guidance or performance benchmarks for the practice.

8.1.6. Erosion and Sediment Control

Erosion and sediment control are critical to every construction project. Erosion and sediment control predates all other state and federal stormwater management efforts in Virginia. Methods to prevent the export of sediments should be planned during the site design process. These consist of the temporary installation and operation of a series of structural and nonstructural practices (see **Figures 8.1 and 8.2**) throughout the entire construction process to minimize soil erosion and prevent off-site delivery of sediment. Because construction is expected to last for a finite and short period of time, the design standards are usually smaller and thus riskier (25-year

versus the 100-year storm). By phasing construction, thereby limiting the exposure of bare earth at any one time, the risk to the environment is reduced significantly.

The basic practices include clearing limits, dikes, berms, temporary buffers, protection of drainage ways, soil stabilization through hydroseeding or mulching, perimeter controls, and various types of sediment traps and basins. All plans have some component that requires filtration of runoff crossing construction areas to prevent sediment from leaving the site. This usually requires a sediment collection system including, but not limited to, conventional settling ponds and advanced sediment collection devices such as polymer-assisted sedimentation and advanced sand filtration. Silt fences are commonly specified to filter distributed flows, and they require maintenance and replacement after storms. Filter systems are added to inlets until the streets are paved and the surrounding area has a cover of vegetation. Sediment basins are constructed to filter out sediments through rock filters, or are equipped with floating skimmers or chemical treatment to settle out pollutants. Other common erosion and sediment control measures include temporary seeding and rock or ribbed entrances to construction sites to remove dirt from vehicle tires.

Control of runoff's erosive potential is critical. Most erosion and sediment control manuals provide design guidance on the capacity and ability of swales to handle runoff without eroding, on the design of flow paths to transport runoff at non-erosive velocities, and on the dissipation of energy at pipe outlets. Examples include rock energy dissipators, level spreaders, and other such devices. Although erosion and sediment control practices are temporary, they require constant operation and maintenance during the complicated sequence of construction and after major storm events. It is exceptionally important to ensure that practices are frequently inspected and repaired and that sediments are cleaned out.

In Virginia, Erosion and Sediment Control is the subject of a completely separate regulatory program (§ 62.1-44.15:51 *et seq.*, Code of Virginia; 4 VAC 50-30 *et seq.*; *Virginia Erosion and Sediment Control Handbook, Third Edition*, 1992) and is not addressed further in this Handbook.



Figure 8.1. Temporary Silt Fence



Figure 8.2. Temporary Sediment Basin

8.1.7. Reforestation and Soil Compost Amendments

This set of practices seeks to improve the quality of native vegetation and soils present at the site. Depending on the ecoregion, this may involve forest or meadow plantings, tilling, and amending compacted soils to improve their hydrologic properties.

The goal is to maintain as much predevelopment hydrologic function at a development site as possible by retaining canopy interception, duff/soil layer interception, evapotranspiration, and surface infiltration. The basic methods to implement this practice are described in Cappiella et al. (2006), Pitt et al (2005), Chollak and Rosenfeld (1998), and Balusek (2003).

At this time, there are few monitoring data to assess the degree to which land reforestation or soil amendments can improve the quality of stormwater runoff at a particular development site, apart from the presumptive watershed research that has shown that forests with undisturbed soils have very low rates of surface runoff and extremely low levels of pollutants in runoff (Singer and Rust, 1975; Johnson et al., 2000; Chang, 2006). More data are needed on the hydrologic properties of urban forests and soils whose ecological functions are stressed or degraded by the urbanization process (Pouyat et al., 1995, 2007).

8.1.8. Pollution Prevention BMPs

By far the most effective control of NPS pollution is to *prevent its release*. This is especially true for stormwater hotspots. There are three families of runoff pollution prevention:

- Impervious surface reductions: reducing the amount of hard surfaces;
- Housekeeping techniques: basic clean-up and management practices;
- Construction practices (see E&S control above): techniques to prevent exposed soils from eroding, methods to reduce opportunities for sediment release into stormwater, and methods to catch sediment already suspended in stormwater

The stormwater-related problems associated with hotspots were described in **Chapter 6**. The keys to managing and treating runoff at hotspot sites are as follows:

- **Prevention.** The goal of pollution prevention is to prevent contact of rainfall or stormwater runoff with pollutants, and it is an important element of the post-construction stormwater plan. It is most important to design manage and store toxic materials on the site in a way that prevents opportunities for the pollutants to be exposed to rain and be washed into runoff.
- **Provide pre-treatment** devices between the source material and any stormwater control measures used to control general runoff from the site, especially if they involve infiltration. **Table 8.3** provides a matrix that indicates which control measures are appropriate for use at hotspot locations.

- **Inspect and correctly maintain** all pollution prevention or treatment elements at the site on a routine basis. Because of the extremely toxic nature of hotspot pollutants, it is extremely important that the stormwater control measures at hotspot sites be kept in good working order.
- **Train personnel** at the affected area to ensure that industrial and municipal managers and employees understand and implement the correct stormwater pollution prevention practices needed for their site or operation.

8.1.9. Runoff Volume Reduction – Rainwater Harvesting

A primary goal of stormwater management is to reduce the volume of runoff from impervious surfaces. There are several classes of BMPs that can achieve this goal, including rainwater harvesting systems, vegetated BMPs that evaporate and transpire part of the volume, and infiltration BMPs. For all of these measures, the amount of runoff volume to be captured depends on watershed goals, site conditions including climate, upstream nonstructural practices employed, and whether the chosen BMP is the sole management measure or part of a treatment train. Generally, runoff volume reduction BMPs are designed to handle at least the Treatment Volume from impervious surfaces (first 1-inch of rainfall). In Virginia, control of the 1-year 24-hour storm volume is considered the standard necessary to protect stream channel geomorphology, while base flow recharge can be addressed by capturing a much smaller volume (see **Chapter 10**).

Some designers have reported that in areas with medium to lower percentage of impervious surfaces, they are able to control up to the 100-year storm by enlarging runoff volume reduction BMPs and applying them to the entire site. In retrofit situations, capture amounts as small as 1 cm are a distinct improvement. It should be noted that there are important, although indirect, water quality benefits of all runoff volume reduction BMPs: (1) the reduction in runoff will reduce streambank erosion downstream and the concomitant increases in sediment load, and (2) volume reductions lead to pollutant mass load reductions, even if pollutant concentrations in stormwater are not decreased.

Rainwater harvesting systems refer to the use of captured runoff from roof tops in rain barrels, rain tanks, or cisterns (**Figures 8.3 and 8.4** below). This BMP treats runoff as a resource and is one of the few BMPs that can provide a tangible economic benefit through the reduction of treated water usage. Rainwater harvesting systems have substantial potential as retrofits via the use of rain barrels or cisterns that can replace lawn or garden sprinkling systems. Use of this BMP to provide gray water within buildings (e.g., for toilet flushing) is considerably more complicated due to the need to construct new plumbing and obtain the necessary permits.

The greatest challenge with these systems is the need to use the stored water and avoid having full tanks when the next storm occurs. That is, these BMPs are effective only if the captured runoff can be regularly used for some gray water usage, like car washing, toilet flushing, or irrigation (e.g., golf courses, landscaping, nurseries). In some areas it might be possible to use the water for drinking, showering, or washing, but treatment to potable water quality would be required. Sizing of the required storage is dependent on the climate patterns, the amount of

impervious cover, and the frequency of water use. Areas with frequent rainfall events require less storage as long as the water is used regularly, while areas with cold weather will not be able to utilize the systems for irrigation in the winter, and thus require larger storage.

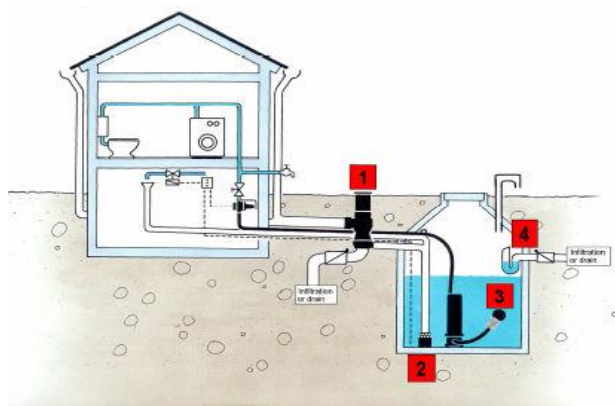


Figure 8.3. Rainwater Harvesting Schematic



Figure 8.4 Above-Ground Rain Tanks

One substantial advantage of these systems is their ability to reduce water costs for the user and the ability to share needs. An example of this interaction is the Pelican Hill development in Irvine, California, where excess runoff from the streets and houses is collected in enormous cisterns and used for watering of a nearby golf course. Furthermore, compared to other BMPs, the construction of rainwater harvesting facilities provides a long term benefit with minimal maintenance cost, although they do require an up-front investment for piping and storage tanks.

Coombes et al. (2000) found that rainwater harvesting achieved a 60-90 percent reduction in runoff volume. However, in general, few studies have been conducted to determine the performance of these BMPs. It should be noted that rainwater harvesting systems do collect airborne deposition and acid rain.

8.1.10. Runoff Volume Reduction

Runoff Volume Reduction – Vegetated

A large and very promising class of BMPs includes those that use infiltration and evapotranspiration via vegetation to reduce the volume of runoff. These BMPs also directly address water quality of both surface water and groundwater by reducing streambank erosion, capturing suspended solids, and removing other pollutants from stormwater during filtration through the soil (although the extent to which pollutants are removed depends on the specific pollutant and the local soil chemistry). Depending on their design, these BMPs can also reduce peak flows and recharge groundwater (if they infiltrate). These BMPs can often be added as retrofits to developed areas by installing them into existing lawns, rights-of-way, or traffic islands. They can add also beauty and property value.

Flow volume is addressed by this BMP group by first capturing runoff, creating a temporary holding area, and then removing the stored volume through infiltration and evapotranspiration. Swales refer to grassy areas on the side of the road that convey drainage (**Figure 8.5** below).

These were first designed to move runoff away from paved areas, but they can now be designed to achieve a certain contact time with runoff, so as to promote infiltration and pollutant removal. Bioretention generally refers to a constructed depression or swale that encloses a filter media mix (often sand and organic material), with vegetation growing on top, to which stormwater runoff from impervious surfaces is directed (**Figure 8.6**). The original rain garden or bioretention facilities were constructed with an impermeable liner at the bottom of the prepared soil to prevent infiltration and instead had a low-level outflow at the bottom. Green roofs are very similar to bioretention BMPs (**Figure 8.7**). They tend to be populated with a light expanded shale-type soil and succulent plants chosen to survive wet and dry periods. Finally, bioinfiltration is similar to bioretention, but it is better engineered to achieve greater infiltration (**Figure 8.8**). All of these devices are usually at the upper end of a treatment train and designed for smaller storms, which minimizes their footprint and allows for incorporation within existing infrastructure (such as traffic control devices and median strips). This allows for distributed treatment of the smaller volumes and distributed volume reduction.



Figure 8.5. Vegetated Wet Swale



Figure 8.6. Parking Area Bioretention



Figure 8.7. Vegetated Roof



Figure 8.8. Retrofit Bioinfiltration

These BMPs work by capturing water in a vegetated area, which then infiltrates into the soil below. They are primarily designed to use plant material and soil to evaporate and transpire the runoff over several days following the storm. A shallow depth of ponding is required, since the inflows may exceed the possible infiltration capacity of the native soil. This ponding is

maintained above an engineered sandy soil mixture and is a surface-controlled process (Hillel, 1998). Early in the storm, the soil moisture potential creates a suction process that helps draw water into the BMP. This then changes to a steady rate that is “practically equal to the saturated hydraulic conductivity” of the subsurface (Hillel, 1998). The hydrologic design goal should be to maximize the volume of water that can be held in the soil, which necessitates consideration of the soil hydraulic conductivity (which varies with temperature), climate, depth to groundwater, and time to drain. Usually these devices are designed to empty between 24-72 hours after a storm event. In some cases (usually bioretention), these BMPs have an underdrain.

The choice of vegetation is an important part of the design of these BMPs. Many sites where infiltration is desirable have highly sandy soils, and the vegetation has to be able to endure both wet and dry periods. Long root growth is desired to promote infiltration (Minnesota Council, 2001), and plants that attract birds can reduce the insect population. Bioretention cells may be wet for longer periods than bioinfiltration sites, requiring different plants. Denser plantings or “thorns” may be needed to avoid the destruction caused by humans and animals taking shortcuts through the beds.

The pollutant removal mechanism operating for volume reduction BMPs are different for each pollutant type, soil type, and volume reduction mechanism. For bioretention and BMPs using infiltration, the sedimentation and filtration of suspended solids in the top layers of the soil are extremely efficient. Several studies have shown that the upper layers of the soil capture metals, particulate nutrients, and carbon (Pitt, 1996; Deschesne et al., 2005; Davis et al., 2008).

The removal of dissolved nutrients from stormwater is not as straightforward. While ammonia is caught by the top organic layer, nitrate is mobile in the soil column. Some bioretention systems have been built to hold water in the soil for longer periods in order to create anaerobic conditions that would promote denitrification (Hunt and Lord, 2006). Phosphorus removal is related to the amount of phosphorus in the original soil. Some studies have shown that bioretention cells built with agricultural soils actually *increased* the amount of phosphorus released. Chlorides pass through the system unchecked (Ermilio and Traver, 2006), while oils and greases are easily removed by the organic layer. Hunt et al. (2008) have reported in studies in North Carolina that the drying cycle appears to kill off bacteria. Temperature is not usually a concern, since most storms do not overflow these devices. Green roofs collect airborne deposition and acid rain and may export nutrients when they overflow. However, this must be tempered by the fact that in larger storms, most natural lands would produce nutrients.

A group of new research studies from North America and Australia have demonstrated the value of many of these runoff volume reduction practices to replicate predevelopment hydrology at the site. The results from 11 recent studies are given in **Table 8.1** below, which shows the runoff reduction capability of bioretention. As can be seen, the reduction in runoff volume achieved by these practices is impressive, ranging from 20-99 percent with a median reduction of about 75 percent. Bioswales installed during Seattle’s natural drainage systems project also have demonstrated excellent results (see Horner et al., 2003; Jefferies, 2004; Stagge, 2006). Bioinfiltration has been less studied, but one field study concluded that close to 20 percent of the storm volume was removed by bioinfiltration (Sharkey, 2006). Capture of small storms through

this kind of BMP appears to be extremely effective in areas where the majority of rain falls in smaller storms.

Table 8.1. Volumetric Runoff Reduction Achieved by Bioretention

Bioretention Design	Location	Runoff Reduction	Reference
Infiltration	CT	99%	Dietz and Clausen (2006)
	PA	86%	Ermiliao and Traver (2006)
	FL	98%	Rushton (2002)
	AUS	73%	Lloyd et al. (2002)
Underdrain	ONT	40%	Van Seters et al. (2006)
	Model	30%	Perez-Perdini et al. (2005)
	NC	40-60%	Smith and Hunt (2007)
	NC	20-29%	Sharkey (2006)
	NC	52-56%	Hunt et al. (2008)
	NC	20-50%	Passeport et al. (2008)
	MD	52-65%	Davis et al. (2008)

Source: NRC (2008)

The strengths of vegetated runoff volume reduction BMPs include the flexibility to use the drainage system as part of the treatment train. For example, bioswales can replace drainage pipes, green roofs can be installed on buildings, and bioretention can replace parking borders, thereby reducing the footprint of the stormwater system. Also, through the use of swales and reducing pipes and inlets, costs can be offset. Vegetated systems are more tolerant of the TSS collected, and their growth cycle maintains pathways for infiltration and prevents clogging. Freeze-thaw cycles also contribute to pathway maintenance. The aesthetic appeal of vegetated BMPs is also a significant strength.

Weaknesses include the dependence of these BMPs on native soil infiltration and the need to understand groundwater levels and karst geology, particularly for those BMPs designed to infiltrate. For bioinfiltration and bioretention, most failures occur early on and are caused by sedimentation and construction errors that reduce infiltration capacity, such as stripping off the topsoil and compacting the subsurface. Once a good grass cover is established in the contributing area, the danger of sedimentation is reduced. Nonetheless, the need to prevent sediment from overwhelming these structures is critical. The longevity of these BMPs and their vulnerability to toxic spills are a concern (Emerson and Traver, 2008), as is their failure to reduce chlorides. Finally, in areas where the land use is a hot spot, or where (the BMP could potentially contaminate the groundwater supply, bioretention, non-infiltrating bioswales, and green roofs may be more suitable than infiltration BMPs.

The role of infiltration BMPs in promoting groundwater recharge deserves additional consideration. Although this is a benefit of infiltration BMPs in regions where groundwater levels are dropping, it may be undesirable in a few limited scenarios. For example, in most urban areas, there is so much impervious cover that it would be difficult to “over-infiltrate.” Nonetheless, the use of infiltration BMPs will change local subsurface hydrology, and the ramifications of this – good and bad – should be considered prior to their installation.

Maintenance of vegetated runoff reduction BMPs is relatively simple. A visit after a rainstorm to check for plant health, to check sediment buildup, and to see if the water is ponded can answer many questions. Maintenance includes trash pickup and seasonal removal of dead grasses and weeds. Sediment removal from pretreatment devices is required. Depending on the pollutant concentrations in the influent, the upper layer of organic matter may need to be removed infrequently to maintain infiltration and to prevent metal and nutrient buildup.

At the site level, the chief factors that lead to uncertainty are the infiltration performance of the soil, particularly for the limiting subsoil layer, and how to predict the extent of pollutant removal. Traditional percolation tests are not effective to estimate the infiltration performance; rather, testing hydraulic conductivity is required. Furthermore, the infiltration rate varies depending on temperature and season (Emerson and Traver, 2008). Basing measurements on percent removal of pollutants is extremely misleading, since every site and storm generates different levels of pollutants. The extent of pollutant removal depends on land use, time between storms, seasons, and so forth. These factors should be part of the design philosophy for the site.

Finally, it should also be pointed out that climate is a factor determining the effectiveness of some of these BMPs. For example, green roofs are more likely to succeed in areas having smaller, more frequent storms, compared to areas subject to less frequent, more intense storms.

Runoff Volume Reduction – Subsurface

Infiltration is the primary runoff volume reduction mechanism for subsurface BMPs, such that much of the previous discussion is relevant here. Thus, like vegetated BMPs, these BMPs provide benefits for groundwater recharge, water quality, stream channel protection, peak flow reduction, capture of the suspended solids load, and filtration through the soil (Ferguson, 2002). Because these systems can be built in conjunction with paved surfaces (i.e., they are often buried under parking lots), the amount of water captured, and thus stream protection, may be higher than for vegetated systems. They also have lower land requirements than vegetated systems, which can be an enormous advantage when using these BMPs during retrofitting, as long as the soil is conducive to infiltration.

Similar to vegetated BMPs, this BMP group works primarily by first capturing runoff and then removing the stored volume through infiltration. The temporary holding area is made either of stone or using manufactured vaults. Examples include infiltration trenches, seepage pits (dry wells), and permeable pavement (see **Figures 8.9, 8.10, 8.11, and 8.12** below). As with vegetated BMPs, a shallow depth of ponding is required, since the inflows may exceed the possible infiltration ability of the native soil. In this case, the ponding is maintained within a rock bed under a permeable pavement or in an infiltration trench. These devices are usually designed to empty between 24-72 hours after the storm event.

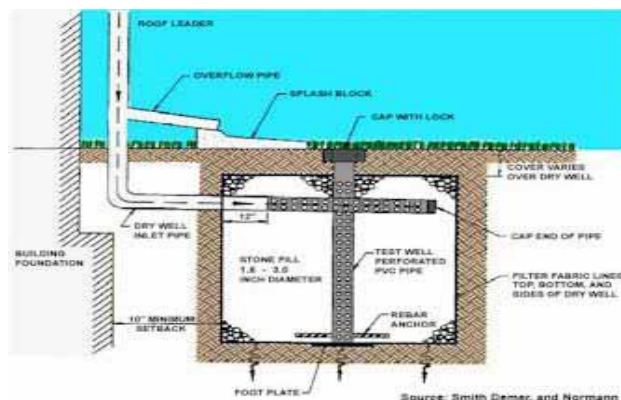


Figure 8.9. Seepage Pit (Dry Well) Schematic



Figure 8.10. Infiltration Trench



Figure 8.11. Porous Asphalt



Figure 8.12. Interlocking Permeable Pavers

The infiltration processes operating for these subsurface BMPs are similar to those for the vegetated devices previously discussed. Thus, much like for vegetated systems, the level of control achieved depends on the infiltration ability of the native soils, the percent of impervious surface area in the contributing watershed, land use contributing to the pollutant loadings, and climate. A large number of recent studies have found that permeable pavement can reduce runoff volume by anywhere from 50 percent (Rushton, 2002; Jefferies, 2004; Bean et al., 2007) to as much as 95 percent or greater (van Seters et al., 2006; Kwiatkowski et al., 2007). Villanova University's Stormwater Research and Demonstration Park has successfully demonstrated a retrofit of standard asphalt with permeable pavement.

The strengths of subsurface runoff volume reduction BMPs are similar to those of their vegetated counterparts. Additional attributes include their ability to be installed under parking areas and to manage larger volumes of rainfall. These BMPs typically have few problems with safety or vector-borne diseases because of their subsurface location and storage capacity, and they can be very aesthetically pleasing. The potential of permeable pavement could be particularly far-reaching if one considers the amount of impervious surface in urban areas that is comprised of roads, driveways, and parking lots.

The weaknesses of these BMPs are also similar to those of vegetated systems, including their dependence on native soil infiltration and the need to understand groundwater levels and karst geology. Simply estimating the soil hydraulic conductivity can have an error rate of an order of magnitude. Specifically for subsurface systems that use geotextiles (not permeable pavement), there is a danger of TSS being compressed against the bottom of the geotextile, preventing infiltration. There are no freeze-thaw cycles or vegetated processes that can reopen pathways, so the control of TSS is even more critical to their life span. In most cases (permeable pavement is an exception), pretreatment is required, except for the cleanest of sources (like a slate roof). Typically, manufactured devices, sediment forebays, or grass filter strips are part of the design of subsurface BMPs to capture the larger sediment particles.

The maintenance of subsurface runoff volume reduction BMPs is relatively simple but critical. If inspection wells are installed, a visit after a rainstorm will check that the volume is captured, and later that it has infiltrated. Porous surfaces should undergo periodic vacuum street sweeping when a sediment source is present. Pretreatment devices require sediment removal. The difficulty with this class of BMPs is that, if a toxic spill occurs or maintenance is not proactive, there are no easy corrective measures other than replacement.

Low Impact Development (LID). LID refers primarily to the use of small, engineered, on-site stormwater practices to treat the quality and quantity of runoff at its source. It is discussed here because the BMPs that are thought of as LID – particularly vegetated swales, green roofs, permeable pavement, and rain gardens – are all runoff volume reduction BMPs. They are designed to capture the first portion of a rainfall event and to treat the runoff from a few hundred square meters of impervious cover.

As discussed earlier, several studies have measured the runoff volume reduction of individual LID practices. Fewer studies are available on whether multiple LID practices, when used together, have a cumulative benefit at the neighborhood or catchment scale. Several monitoring studies have clearly documented a major reduction in runoff from developments that employ LID and Environmental Site Design, compared to those that do not. In addition, six studies have documented the runoff reduction benefits of LID at the catchment or watershed scale, using a modeling approach (Alexander and Heaney, 2002; Stephens et al., 2002; Holman-Dodds et al., 2003; Coombes, 2004; Hardy et al., 2004; and Huber et al., 2006).

8.1.11. Peak Flow Reduction and Runoff Treatment

Peak Flow Reduction

After efforts are made to prevent the generation of pollutants and to reduce the volume of runoff that reaches stormwater systems, stormwater management focuses on the reduction of peak flows and associated treatment of polluted runoff. The main class of BMPs used to accomplish this is pond-type practices, versions of which have dominated stormwater management for decades. These include a wide variety of ponds and wetlands, including wet ponds (also known as retention basins), dry extended detention ponds (also known as detention basins), and constructed wetlands. By holding a volume of stormwater runoff for an extended period of time, pond-type BMPs can achieve both water quality improvement and reduced peak flows.

Generally the goal is to hold the flows for at least 24 hours to maximize the opportunity of settling, adsorption, and transformation of pollutants (based on past pollutant removal studies) (Rea and Traver, 2005). For smaller storm events (one-year storms), this added holding time also greatly reduces the outflows from the BMP to a level that the stream channel can handle. Most wet ponds and stormwater wetlands can hold a “treatment volume,” such that the flows leaving in smaller storms have been held and “treated” for multiple days. Extended detention dry ponds also greatly reduce the outflow peaks to achieve the required residence times.

Usually pond-type devices are lower in the treatment train of BMPs, if not at the very end. This is both due to their function (they are designed for larger events) and because the required water sources and less permeable soils needed for these BMPs are more likely to be found at the lower areas of the site. Some opportunities exist to naturalize dry ponds or to retrofit wet ponds into stormwater wetlands, but it depends on their site configuration and hydrology. A wet pond is shown in **Figure 8.13**. A stormwater wetland and a dry extended basin are shown in **Figures 8.14 and 8.15**.



Figure 8.13. Wet Pond



Figure 8.14. Constructed Wetland



Figure 8.15. Dry Extended Detention Basin

Simple ponds are little more than a hole in the ground, in which stormwater is piped in and out. Dry ponds are meant to be dry between storms, whereas wet ponds have a permanent pool throughout the year. Detention basins reduce peak flows by restricting the outflows and creating a storage area. Depending on the detention time, outflows can be reduced to levels that do not accelerate erosion, that protect the receiving stream channel, and that reduce flooding.

The flow normally enters the structure through a sediment forebay (**Figure 8.16**), which is included to capture incoming sediment, remove the larger particles through settling, and allow for easier maintenance. Then a meandering path or cell structure is built to “extend” and slow down flows. The main basin is a large storage area (sometimes over the meandering flow paths). Finally, the runoff exits through an outflow control structure built to retard flow.



Figure 8.16. Sediment Forebay, with Wet Pond in the Background

Wet ponds, stormwater wetlands, and (to a lesser extent) dry extended detention basins provide treatment. The first step in the pond treatment process is the settling of larger particles in the sediment forebay. Next, for wet ponds a permanent pool of water is maintained so that, for smaller storms, the new flows push out a volume that has had a chance to interact with vegetation and be “treated.” This volume is equivalent to an inch of rain over the impervious surfaces in the drainage area. Thus, what exits the BMP during smaller storm events is base flow contributions and runoff that entered during previous events. For dry extended detention ponds, there is no permanent pool and the outlet is instead greatly restricted. For all of these devices, vegetation is considered crucial to pollutant removal. Indeed, wet ponds are designed with an aquatic bench around the edges to promote contact with plants. The vegetation aids in reduction of flow velocities (through friction), provides growth surfaces for microbes, takes up pollutants such as nutrients, and provides filtering (Braskerud, 2001).

The ability of pond structures to achieve a certain level of control is size related – that is, the more peak flow reduction or pollutant removal required, the more volume and surface area are needed in the basin. Because it is not simply the peak flows that are important, but also the duration of the flows that cause damage to the receiving stream channels (McCuen, 1979; Loucks et al., 2005), some ponds are currently sized and installed in series with runoff volume reduction BMPs.

The strength of pond-type devices is the opportunity to create habitats or picturesque settings in conjunction with stormwater management. The weaknesses of these measures include large land requirements, chloride buildup, possible temperature effects (i.e., warming), and the risk of creating habitat for undesirable species in urban areas. There is a perception that these devices promote mosquitoes, but that has not been found to be a problem when a healthy biological habitat is created (Greenway et al., 2003). Another drawback of this class of BMPs is that they often have limited treatment capacity, in that they can reduce pollutants in stormwater only to a certain level. These so-called irreducible effluent concentrations have been documented mainly for ponds and stormwater wetlands, as well as for sand filters and grass channels (Schueler, 1998). Finally, it should be noted that either a larger watershed (10-25 acres: CWP, 2004) or a continuous water source is needed to sustain wet ponds and stormwater wetlands.

Maintenance requirements for ponds and wetlands include the removal of built-up sediment from the sediment forebay, harvesting of grasses to remove accumulated nutrients, and repair of berms and structures after damaging storm events. Inspection items relate to the maintenance of the dam and sediment forebay.

While the basic hydrologic function of extended detention devices is well known, their performance on a watershed basis is not. Because they do not significantly reduce runoff volume and are designed on a site-by-site basis using synthetic storm patterns, their exclusive use as a flood reduction strategy at the watershed scale is uncertain (McCuen, 1979; Traver and Chadderton, 1992). Much of this variability is reduced when they are coupled with volume reduction BMPs at the watershed level. Pollutant removal is effected by climate, short-circuiting of flows through the device, and by the schedule of sediment removal and plant harvesting. Extreme events can re-suspend captured sediments, thus reintroducing them into the environment. Although it is the subject of much debate, it seems likely that plants will need to be harvested to accomplish nutrient removal (Reed et al., 1998).

Runoff Treatment

As mentioned above, many BMPs associated with runoff volume reduction and extended detention provide a water quality benefit. There are also some BMPs that focus primarily on water quality with little peak flow or volume effect. Designed for smaller storms, these are usually based on filtration, hydrodynamic separation, or small-scale bioretention systems that drain to a subsequent receiving water or other device. Thus, often these BMPs are used in conjunction with other devices in a treatment train or as retrofits under parking lots. They can be very effective as pretreatment devices when used “higher up” in the watershed than infiltration structures. Finally, in some cases these BMPs are specifically designed to reduce peak flows in

addition to providing water quality benefits by introducing elements that make them similar to detention basins. This is particularly the case for sand filters.

The sand filter is relied upon as a treatment technology in many regions, particularly those where stream geomorphology is less of a concern, and thus peak flow control and runoff volume reduction are not the primary goals. These devices can be effective at removing suspended sediments and can extend the longevity and performance of runoff volume reduction BMPs. They are also one of the few urban retrofit practices available, due to the ability to implement them within traditional culvert systems. **Figures 8.17 and 8.18** show designs for the Austin sand filter and Delaware sand filter.



Figure 8.17. Austin Sand Filter



Figure 8.18. Delaware Sand Filter

Filters use sand, peat, or compost to remove particulates, similar to the processes used in drinking water treatment plants. Sand filters primarily remove suspended solids and ammonia nitrogen. Biological material, such as peat or compost, provides adsorption of contaminants such as dissolved metals, hydrocarbons, and other organic chemicals.

Manufactured Treatment Devices (MTDs)

There are several types of manufactured stormwater treatment devices in the marketplace, and more are being designed all the time. Hydrodynamic devices use rotational forces to separate the solids from the flow, allowing the solids to settle out of the flow stream. There is a recent class of bioretention-like manufactured devices that combine inlets with planters. In these systems, small volumes are directed to a soil planter area, with larger flows bypassing and continuing down the storm sewer system. In any event, for manufactured treatment devices (MTDs) the user needs to look to the manufacturer's published and reviewed data to understand how the device should be applied.

The level of control that can be achieved with these BMPs depends entirely on sizing of the device based on the incoming flow and pollutant loads. Each unit has a certified removal rate depending on inflow to the BMP. Also, all units have a maximum volume or rate of flow they can treat, such that higher flows are bypassed with no treatment. Thus, the user has to determine what size unit is needed and the number to use, based on the area's hydrologic cycle and what criteria are to be met.

With the exception of some types of sand filters, the strengths of water quality treatment BMPs are that they can be placed within existing infrastructure or under parking lots, and thus do not take up land that may be used for other purposes. They make excellent choices for retrofit situations. For filters, there is a wealth of experience from the water treatment community on their operations. There are several testing protocols, including the new Virginia Technology Assessment Protocol (VTAP), that have been established to validate the performance of MTDs (the sufficiency of the testing protocols is discussed below).

Weaknesses of these devices include their cost and maintenance requirements. Regular maintenance and inspection at a high level are required to remove captured pollutants, to replace mulch, or to rake and remove the surface layer to prevent clogging. In some cases, specialized equipment (vacuum trucks) is required to remove built-up sediment. Although the underground placement of these devices has many benefits, it makes it easy to neglect their maintenance because there are no signs of reduced performance on the surface. Because these devices are manufactured, the unit construction cost is usually higher than for other BMPs. Finally, the numerous testing protocols are confusing and inhibit more widespread applications.

The chief uncertainty with these BMPs is due to the lack of certification of some MTDs. There is also concern about which pollutants are removed by which class of device. For example, hydrodynamic devices and sand filters do not address dissolved nutrients, and in some cases convert suspended pollutants to their dissolved form. Both issues are related to the false perception that a single BMP must be found that will comprehensively treat stormwater. Such pressures often put vendors in a position of trying to certify that their devices can remove *all* pollutants. Most often, these devices can serve effectively as part of a treatment train, and they should be valued for their incremental contributions to water quality treatment. For example, a filter that removes sediment upstream of a bioinfiltration BMP can greatly prolong the life of the infiltration device.

Testing of MTDs

Manufacturers of proprietary BMPs offer a service that can save municipalities/developers time and money. Time is saved by the ability of the manufacturers to quickly select a model matching the needs of the site. A city can minimize the cost of buying the product by requiring the different manufacturers to submit bids for the site. All the benefits of the service will have no meaning, however, if the cities/developers cannot trust the performance claims of the different products. Because the United States does not have, at this time, a national program to verify the performance of MTDs, interested municipalities and developers face a high amount of uncertainty when they select a product. Money could be wasted on products that might have the lowest bid, but do not achieve the water quality goals of the municipality or state.

The U.S. EPA's Environmental Technology Verification (ETV) program was created to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The Wet Weather Flow Technologies Pilot project was established as part of the ETV program to verify commercially available technologies used in the abatement and control of urban stormwater runoff, combined sewer overflows, and

sanitary sewer overflows. Ten proprietary BMPs were tested under the ETV program, and the results of the monitoring are available on the National Sanitation Foundation website. Unfortunately, the funding for the ETV program was discontinued before all the stormwater products could be tested. Without a national testing program, some states have taken a more regional approach to verifying the performance of proprietary practices, while most states do not have any type of verification or approval program.

The Washington Department of Ecology has supported a testing protocol called Technology Assessment protocol – Ecology (TAPE) that describes a process for evaluating and reporting on the performance and appropriate uses of emerging MTDs. California, Massachusetts, Maryland, New Jersey, Pennsylvania, and Virginia have sponsored a testing program called Technology Acceptance and Reciprocity Partnership (TARP), through which a number of products are being tested in the field. The state of Wisconsin has prepared a draft technical standard (2006) describing methods for predicting the site-specific reduction efficiency of proprietary sedimentation devices. To meet the criteria in the standard, the manufacturers can either use a model to predict the performance of the practice or complete a laboratory protocol designed to develop efficiency curves for each product. Although none of these state or federal verification efforts have produced enough information to sufficiently reduce the uncertainty in selection and sizing of MTDs, many proprietary practices are being installed around the country, because of the perceived advantage of the service being provided by the manufacturers and the sometimes overly optimistic performance claims.

All those involved in stormwater management, including the manufacturers, will have a much better chance of implementing a cost-effective stormwater program in their cities if the barriers to a national testing program for MTDs are eliminated. Two of the barriers to the ETV program were high cost and the transferability of the results. Also, the ETV testing did not produce results that could be used in developing efficiency curves for the product. There have been discussions about establishing a new national testing program that could reduce testing costs by using laboratory testing instead of field testing. However, many consider field testing to be very important to determine if laboratory test results are actually transferrable to the real world. The new VTAP is Virginia's method of building upon the other existing protocols to better evaluate how MTDs perform. The VTAP will be implemented through the DEQ's Virginia Stormwater BMP Clearinghouse.

8.1.12. Aquatic Buffers and Managed Floodplains

Establishing aquatic buffers, also called stream buffers or riparian buffers (**Figures 8.21 and 8.22** below), involves reserving a vegetated zone adjacent to streams, shorelines, or wetlands in response to development regulations or a local ordinance. In most regions of the country, including Virginia, forest vegetation is preferred. When properly designed, buffers can both reduce runoff volumes and provide water quality treatment of stormwater.

The performance of urban stream buffers cannot be predicted from studies of buffers installed to remove sediment and nutrients from agricultural areas (Lowrance and Sheridan, 2005). Agricultural buffers have been reported to have high sediment and nutrient removal because they intercept sheet flow or shallow groundwater flow in the riparian zone. By contrast, urban stream

buffers often receive concentrated surface runoff or may even have a storm drain pipe that short-circuits the buffer and directly discharges into the stream. Consequently, the pollutant removal capability of urban stream buffers is limited, unless they are specifically designed to distribute and treat stormwater runoff (NRC, 2000). This involves the use of level spreaders, grass filters, and berms to transform concentrated flows into sheet flow (Hathaway and Hunt, 2006). Such designed urban stream buffers have been applied widely in the Neuse River basin in North Carolina and in Henrico County in Virginia to reduce urban stormwater nutrient inputs to nutrient-sensitive water bodies.



Figure 8.19. Buffered Stream



Figure 8.20. Residential Riparian Buffer

The primary benefit of buffers is to help maintain aquatic biodiversity within the stream. Numerous researchers have evaluated the relative impact of riparian forest cover and impervious cover on stream geomorphology, aquatic insects, fish assemblages, and various indexes of biotic integrity. As a group, the studies suggest that indicator values for urban stream health increase when riparian forest cover is retained over at least 50 to 75 percent of the length of the upstream network (Goetz et al., 2003; Wang et al., 2003; McBride and Booth, 2005; Moore and Palmer, 2005). There is also general agreement that buffering headwater streams is more important than buffering higher order streams, since the headwaters provide the foundation for the aquatic food chain and ecologic health.

The width of the buffer is also important for enhancing its stream protection benefits. Recommended widths range from 25 to 200 feet depending on stream order, protection objectives, and community ordinances. Eastern Virginia communities subject to the Chesapeake Bay Preservation Act (CBPA) are required to designate lands near streams, rivers and open water as Resource Protection Areas, part of which is a 100-foot wide riparian buffer next to the water. Some other Virginia communities, as well, have added buffer requirements to their local codes to protect water quality, biodiversity, and general stream health. However, the beneficial impact of riparian forest cover may diminish as watershed impervious cover grows beyond 15 percent, when degradation by stormwater runoff can overwhelm the benefits of the riparian forest (Roy et al., 2005, 2006; Walsh et al., 2007).

Maintenance, inspection, and compliance for buffers can be a problem. In most communities, urban stream buffers are simply a line on a map and are not managed in any significant way after

construction is over. As such, urban stream buffers are prone to residential encroachment and clearing, and to colonization by invasive plants.

Another important practice is to protect, preserve, or otherwise manage the ultimate 100-year floodplain so that vulnerable property and infrastructure are not damaged during extreme floods. Federal Emergency Management Agency (FEMA), state, and local requirements often restrict or control development on land within the floodway or floodplain. In larger streams, the floodway and aquatic buffer can be integrated together to achieve multiple social objectives.

8.1.13. Stream Rehabilitation

While not traditionally considered an BMP, certain stream rehabilitation practices or approaches can be effective at recreating stream physical habitat and ecosystem function lost during urbanization. When combined with effective BMPs in upland areas, stream rehabilitation practices can be an important component of a larger strategy to address stormwater. From the standpoint of mitigating stormwater impacts, four types of urban stream rehabilitation are common:

- Practices that stabilize streambanks and/or prevent channel erosion/enlargement can reduce downstream delivery of sediments and attached nutrients (**Figures 8.21 and 8.22**). Although the magnitude of sediment delivery from urban-induced stream channel enlargement is well documented, there are very few published data to quantify the potential reduction in sediment or nutrients from subsequent channel stabilization.



Figure 8.21. Before Stream Restoration



Figure 8.22. After Stream Restoration

Streams can be hydrologically reconnected to their floodplains by building up the profile of incised urban streams using grade controls so that the channel and floodplain interact to a greater degree. Urban stream reaches that have been so rehabilitated have increased nutrient uptake and processing rates and, in particular, increased denitrification rates, compared to degraded urban streams prior to treatment (Bukavecas, 2007; Kaushal et al., 2008). This suggests that urban stream rehabilitation may be one of many elements that can be considered to help decrease loads in nutrient-sensitive watersheds.

- Practices that enhance in-stream habitat for aquatic life can improve the expected level of stream biodiversity. However, Konrad (2003) notes that improvement of biological diversity of urban streams should still be considered an experiment, since it is not always clear what hydrologic, water quality, or habitat stressors are limiting. Larson et al. (2001) found that physical habitat improvements can result in no biological improvement at all. In addition, many of the biological processes in urban stream ecosystems remain poorly understood, such as carbon processing and nutrient uptake.
- Some stream rehabilitation practices can indirectly increase stream biodiversity (such as riparian reforestation, which could reduce stream temperatures, and the removal of barriers to fish migration).

It should be noted that the majority of urban stream rehabilitation projects undertaken in the United States are designed for purposes other than mitigating the impacts of stormwater or enhancing stream biodiversity or ecosystem function (Bernhardt et al., 2005). Most stream rehabilitation projects have a much narrower design focus, and are intended to protect threatened infrastructure, naturalize the stream corridor, achieve a stable channel, or maintain local streambank stability (Schueler and Brown, 2004). Improvements in either biological health or the quality of stormwater runoff have rarely been documented.

Unique design models and methods are required for urban streams, compared to their natural or rural counterparts, given the profound changes in hydrologic and sediment regime and stream-floodplain interaction that they experience (Konrad, 2003). While a great deal of design guidance on urban stream rehabilitation has been released in recent years (FISRWG, 2000; Doll and Jennings, 2003; Schueler and Brown, 2004), most of the available guidance has not yet been tailored to produce specific outcomes for stormwater mitigation, such as reduced sediment delivery, increased nutrient processing, or enhanced stream biodiversity. Indeed, several researchers have noted that many urban stream rehabilitation projects fail to achieve even their narrow design objectives for a wide range of reasons (Bernhardt and Palmer, 2007; Sudduth et al., 2007). This is not surprising given that urban stream rehabilitation is relatively new and rarely addresses the full range of in-stream alteration generated by watershed-scale changes. This shortfall suggests that much more research and testing are needed to ensure that urban stream rehabilitation can meet its promise as an emerging BMP.

8.1.14. Municipal Housekeeping

Phase II NPDES/VPDES stormwater permits specifically require municipal good housekeeping as one of the six minimum management measures for MS4s. Although the EPA has not presented definitive guidance on what constitutes “good housekeeping,” CWP (2008a) outlines ten municipal operations where housekeeping actions can improve the quality of stormwater, including the following:

- Municipal hotspot facility management;
- Municipal construction project management;
- Road maintenance;
- Street sweeping;

- Storm drain maintenance;
- Stormwater hotline response;
- Landscape and park maintenance;
- BMP maintenance; and
- Employee training.

The overarching theme is that good housekeeping practices at municipal operations provide source treatment of pollutants before they enter the storm drain system. The most frequently applied practices are street sweeping (**Figure 8.23**) and sediment cleanouts of sumps and storm drain inlets (**Figure 8.24**). Most communities conduct both operations at some frequency for safety and aesthetic reasons, although not specifically for the sake of improving stormwater quality (Law et al., 2008).



Figure 8.23. Street Sweeping



Figure 8.24. Catch Basin Cleaning

Numerous performance monitoring studies have been conducted to evaluate the effect of street sweeping on the concentration of stormwater pollutants in downstream storm drain pipes (see Pitt, 1979; Bender and Terstriep, 1994; Brinkman and Tobin, 2001; Zarrielo et al., 2002; Chang et al., 2005; USGS, 2005; Law et al., 2008). The basic finding is that regular street sweeping has a low or limited impact on stormwater quality, depending on street conditions, sweeping frequency, sweeper technology, operator training, and on-street parking. Sweeping will always have a limited removal capability because rainfall events frequently wash off pollutants before the sweeper passes through, and only some surfaces are accessible to the sweeper, thus excluding sidewalk, driveways, and landscaped areas. However, frequent sweeping (i.e., weekly or monthly) has a moderate capability to remove sediment, trash and debris, coarse solids, and organic matter.

Fewer studies have been conducted on the pollutant removal capability of frequent sediment cleanout of storm drain inlets, most in regions with arid climates (Lager et al., 1977; Mineart and Singh, 1994; Morgan et al., 2005). These studies have shown some moderate pollutant removal if cleanouts are done on a monthly or quarterly basis. Most communities, however, report that they clean out storm drains on an annual basis or in response to problems or drainage complaints (Law, 2006).

Frequent sweeping and cleanouts conducted on the dirtiest streets and storm drains appear to be the most effective way to include these operations in the stormwater treatment train. However,

given the uncertainty associated with the expected pollutant removal for these practices, street sweeping and storm drain cleanout cannot be relied on as the sole BMPs for an urban area.

8.1.15. Illicit Discharge Detection and Elimination

MS4 communities must develop a program to detect and eliminate illicit discharges to their storm drain system as a stormwater NPDES/VPDES permit condition. Illicit discharges can involve illegal cross-connections of sewage or washwater into the storm drain system or various intermittent or transitory discharges due to spills, leaks, dumping, or other activities that introduce pollutants into the storm drain system during dry weather. National guidance on the methods to find and fix illicit discharges was developed by Brown et al. (2004). Local illicit discharge detection and elimination (IDDE) programs represent an ongoing and perpetual effort to monitor the network of pipes and ditches to prevent pollution discharges.

The water quality significance of illicit discharges has been difficult to define since they occur episodically in different parts of a municipal storm drain system. Field experience in conducting outfall surveys does indicate that illicit discharges may be present at 2-5 percent of all outfalls at any given time. Given that pollutants are being introduced into the receiving water during dry weather, illicit discharges may have an amplified effect on water quality and biological diversity.

Many communities indicate that they employ a citizen hotline to report illicit discharges and other water quality problems (Brown et al., 2004), which sharply increases the number of illicit discharge problems observed.

8.1.16. Stormwater Management Education

Like IDDE, public information and education about stormwater is one of the six minimum management measures that MS4 communities must address in their stormwater NPDES/VPDES permits. Stormwater education involves municipal efforts to make sure individuals understand how their daily actions can positively or negatively influence water quality and work to change specific behaviors linked to specific pollutants of concern (Schueler, 2001c). Targeted behaviors include lawn fertilization and pesticide application, clipping and leaf disposal, littering, car fluid recycling, car washing, household hazardous waste management, septic system maintenance, and pet waste pickup.

Communities may use a wide variety of messages to make the public aware of the behavior and more desirable alternatives through internet websites, utility bill inserts, brochures and fact sheets, radio, television, newspaper ads, special events, workshops, or door-to-door outreach by volunteer educators. Communities can also coordinate programs to engage citizens in stormwater pollution prevention and watershed management activities, such as stream monitoring, stream clean-ups, adopt-a-stream programs, tree planting days, and storm drain stenciling.

Several communities have performed before-and-after surveys to assess both the penetration rate for these campaigns and their ability to induce changes in actual behaviors. Significant changes in behaviors have been recorded (see Schueler, 2002), although few studies are available to link

specific stormwater quality improvements to the educational campaigns (but see Turner, 2005; CASQA, 2007).

8.1.17. Residential Stewardship

This BMP involves municipal programs to enhance residential stewardship to improve stormwater quality. Residents can undertake a wide range of activities and practices that can reduce the volume or quality of runoff produced on their property or in their neighborhood as a whole. This may include installing rain barrels or rain gardens, planting trees, xeriscaping, downspout disconnection, storm drain marking, household hazardous waste pickups, proper disposal of waste oil products (**Figure 8.25**), carefully managing application of de-icing products to sidewalks and driveways, and yard waste composting (CWP, 2005). This expands on stormwater education in that a municipality provides a convenient delivery service to enable residents to engage in positive watershed behavior.

The effectiveness of residential stewardship is enhanced when carrots are provided to encourage the desired behavior, such as subsidies, recognition, discounts, and technical assistance (CWP, 2005). Consequently, communities need to develop a targeted program to educate residents and help them engage in the desired behavior.



Figure 8.25. Don't Pour Waste Oil Products Down the Storm Drain!

8.2. OVERVIEW OF POST-CONSTRUCTION BMPs

This section generally describes the post-construction Stormwater Control Measures (BMPs) that may be used in Virginia to manage stormwater runoff. Given the large number and wide variety of MTDs in the marketplace and the pace at which new devices are being introduced, this Handbook will not provide any detail about such devices. However, additional information can be found at the Virginia Stormwater BMP Clearinghouse web site at <http://www.vwrrc.vt.edu/swc/> and in Minton (2005). More specific information about ESD practices and techniques can be found in CWP (1998a). The various BMPs were selected based on their ability to achieve, at varying degrees, the following:

1. Can capture and treat the full Treatment Volume (T_v)
2. Can reduce the volume of stormwater runoff

3. Can remove total phosphorus (TP) from site runoff (regulatory compliance criteria)
4. Can remove total nitrogen (TN) from site runoff
5. Can remove total suspended solids (TSS) from runoff
6. Can remove other pollutants as well (e.g., hydrocarbons, bacteria, metals)
7. Can address stormwater quantity (channel protection criteria, and flood protection) criteria
8. Have acceptable longevity in the field, when maintained properly.

8.2.1. Pollutant Removal Mechanisms

Stormwater control measures remove pollutants from stormwater runoff through various physical, chemical, and biological processes. **Table 8.2** lists the major stormwater pollutant removal processes and the affected stormwater pollutants.

Table 8.2. Stormwater Pollutant Removal Processes

Process	Pollutants Affected
Gravity settling of particulate pollutants	Solids, BOD, pathogens, particulate COD, phosphorus, nitrogen, synthetic organics, particulate metals
Filtration and physical straining of pollutants through a filter media or vegetation	Solids, BOD, pathogens, particulate COD, phosphorus, nitrogen, synthetic organics, particulate metals
Infiltration of particulate and dissolved pollutants	Solids, BOD, pathogens, particulate COD, phosphorus, nitrogen, synthetic organics, particulate metals
Adsorption on particulates and sediments	Dissolved phosphorus, metals, synthetic organics
Photodegradation	COD, petroleum hydrocarbons, synthetic organics, pathogens
Gas exchange and volatilization	Volatile organics, synthetic organics
Biological uptake and biodegradation	BOD, COD, petroleum hydrocarbons, synthetic organics, phosphorus, nitrogen, metals
Chemical precipitation	Dissolved phosphorus, metals
Ion exchange	Dissolved metals
Oxidation	COD, petroleum hydrocarbons, synthetic organics
Nitrification and denitrification	Ammonia, nitrate, nitrite
Density separation and removal of floatables	Petroleum hydrocarbons

Source: NRC (2008)

Since many pollutants in urban stormwater runoff are attached to solid particles, treatment practices designed to remove suspended solids from runoff will remove other pollutants as well. Exceptions to this rule include nutrients, which are often in a dissolved form, soluble metals and organics, and extremely fine particulates (i.e., having a diameter smaller than 10 microns), which can only be removed by treatment practices other than traditional separation methods.

8.2.2. Approved Virginia Non-Proprietary Stormwater Control Measures

Virginia's approved BMPs can be organized into five groups, from rooftop to stream:

- Runoff volume reduction – primary benefit is reducing the volume of runoff leaving the site
- Swales or open channels – runoff conveyance practices that also provide various levels of pollution removal
- Filtering systems – primary benefit is removing nutrients, sediment, heavy metals, grease and oil from runoff
- Infiltration practices – these combine runoff volume reduction (runoff soaks into the soil) and pollution treatment (primarily from filtering)
- Basins –reduce the rate of runoff (detention), also improve pollution removal (wet ponds), and also add wildlife habitat (constructed wetlands)

8.2.2.1. Runoff Volume Reduction

1. **Vegetated Roof (#5) (Figure 8.26).** Vegetated roofs (also known as *green roofs* or *eco roofs*) are alternative roof surfaces that typically consist of waterproofing and drainage materials and an engineered growing media that is designed to support plant growth. Vegetated roofs capture and temporarily store stormwater runoff in the engineered growing media before it is conveyed into the storm drain system. A portion of the captured stormwater evaporates or is taken up by plants, which helps reduce runoff volumes, peak runoff rates, and associated pollutant loads. The water quality treatment processes exhibited by vegetated roofs are runoff volume reduction and plant uptake (biological transformation).



Figure 8.26. Vegetated Roof



Figure 8.27. Downspout Disconnection

2. **Downspout Disconnection (#1) (Figure 8.27).** This strategy involves treating runoff close to its source by intercepting rooftop runoff and infiltrating, filtering, treating, or reusing it before it moves from the roof into the storm drain system. Two kinds of practices are allowed. The first is for simple rooftop disconnection, whereas the second involves disconnection combined with supplementary runoff treatment, including the following:

- Compost amended soils in the filter path
- Installation of dry wells or french drains

- Installation of rain gardens or front yard bioretention
- Storage and reuse in a rain tank or cistern
- Storage and release in a foundation planter

The water quality treatment processes exhibited by downspout disconnection vary, depending upon the supplementary treatment practices used. Simple disconnection and rainwater harvesting (rain tanks or cisterns) rely on the processes of runoff volume reduction, settling (sedimentation), and filtering (filtration). The various forms of supplemental infiltration add the processes of adherence (sorption) to the soil and plant uptake (biological transformation) or removal by bacteria.

3. ***Rainwater Harvesting (#6) (Figure 8.28).*** Rain tanks intercept, divert, store, and release rainfall for future use. The term *Rainwater Harvesting* is used as the title of this specification, but it is also known as a cistern or rain tank system. Rainwater that falls on a rooftop is collected and conveyed into an above- or below-ground storage tank where it can be used for landscape irrigation, non-potable water, and on-site stormwater disposal. Typically, pre-fabricated rain tanks range from 200 to 10,000 gallons in size. The capture and re-use of rainwater can significantly reduce stormwater runoff volumes and pollutant loads (through the water quality treatment processes of runoff volume reduction and sedimentation). By providing a reliable and renewable source of water to end users, rain tanks can also have environmental and economic benefits beyond stormwater management (increased water conservation, water supply during drought, decreased demand on municipal or groundwater supply, etc). Rain tanks can be combined with other on-site practices, such as rain gardens, to enhance their runoff reduction and nutrient removal capability. The water quality treatment processes exhibited by rainwater harvesting practices are runoff volume reduction, settling (sedimentation), and filtering (filtration).



Figure 8.28.. Rainwater Harvesting Tank



**Figure 8.29. Filter Strip with Level Spreader
(gravel pad as pre-treatment)**

4. ***Soil Compost Amendments (#4).*** Soil restoration is an ESD practice applied after construction to restore soil porosity by adding compost and tilling it deep into the soil profile. These soil amendments can reduce the generation of runoff from compacted urban lawns and may also be used to enhance the runoff reduction performance of downspout disconnections,

grass channels, filter strips, and tree clusters. The water quality treatment process exhibited by soil compost amendments are those of infiltration practices: runoff volume reduction, settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, and plant uptake (biological transformation) or removal by bacteria.

5. ***Sheet Flow to Vegetated Filters or Conserved Open Space (#2) (Figure 8.29).*** Filter strips are vegetated areas that treat sheet flow delivered from adjacent impervious areas by slowing runoff velocities and allowing sediment and attached pollutants to settle out. The two design variants are (1) sheet flow into a conserved natural area, and (2) sheet flow to a grass filter strip. The design, installation and management of these design variants are quite different. In some cases, filter strips can treat concentrated flows, but only if the concentrated flow is converted to sheet flow by an engineered level spreader. The water quality treatment processes employed by filter strips are runoff volume reduction, settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, and plant uptake (biological transformation).

8.2.2.2. Swales or Open Channels

The following practices are explicitly designed to capture and treat the full Treatment Volume (T_v) within dry or wet cells formed by check dams or other means, or within the channel itself through a slow velocity and relatively long resistance time.

1. ***Grass Channel (#3) (Figure 8.30 below).*** Grass Channels can provide runoff filtering and treatment within the conveyance system and produce less runoff and pollutants than a traditional system of curb and gutter, storm drain inlets, and pipes. Grass channels provide a modest amount of runoff reduction and pollutant removal that varies depending on the underlying soil permeability. Grass Channels, however, are not capable of providing the same stormwater functions as Dry Swales, since they lack the engineered soil media and storage volumes. Their runoff reduction performance can be boosted when Soil Compost Amendments are added to the bottom of the swale. Grass channels are a preferable alternative to both curb and gutter and storm drains as a stormwater conveyance system where development density, topography and soils permit. The water quality treatment processes employed by grass channels are runoff volume reduction (minimal), settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, and plant uptake (biological transformation).
2. ***Dry Swale (#10) (Figure 8.31 below).*** While Grass Channels and Dry Swales are both considered variations of the open channel concept, they are fundamentally different in terms of their designs. Dry swales are essentially volume-based shallow bioretention cells that are configured as a linear channel that temporarily stores and then filters the desired Treatment Volume. Grass channels are conveyance systems that can provide water quality treatment based on flow rate-based design criteria.



Figure 8.30. Grass Channel

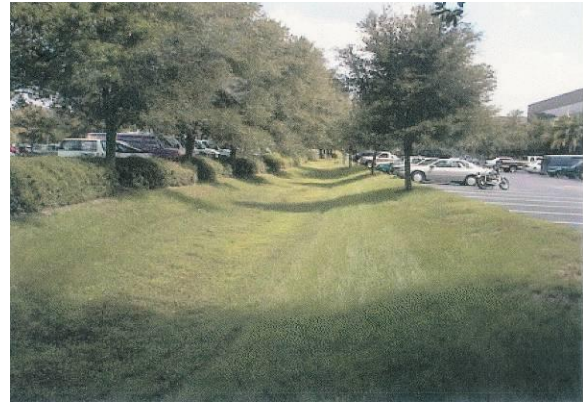


Figure 8.31. Dry Swale

Dry Swales rely on the same pre-mixed soil media filter below the channel as is used for bioretention practices. If soils are extremely permeable, runoff infiltrates into underlying soils. In most cases, however, the runoff treated by the soil media flows into an underdrain, which conveys treated runoff back to the conveyance system further downstream. The underdrain system consists of a perforated pipe within a gravel layer on the bottom of the swale. Dry Swales may appear as simple grass channels with similar shape and turf cover, while others may have more elaborate landscaping. Dry Swales can be planted with turf grass, tall meadow grasses, decorative herbaceous cover, or trees. The water quality treatment processes employed by Dry Swales are runoff volume reduction, settling (sedimentation), filtering (filtration), sorption to the soil, and plant uptake (biological transformation).

8.2.2.3. Filtering Systems

The following practices capture and temporarily store the Treatment Volume (T_v) before passing it through a filter bed of sand, organic matter, soil, or other media.

1. **Filtering Practices (#12) (Figure 8.32 below).** Employing stormwater filters is a useful practice to treat stormwater runoff from small, highly impervious sites. Stormwater filters capture, temporarily store, and treat stormwater runoff by passing it through an engineered filter media, collecting it in an underdrain, and then returning it back to the storm drain system. The filter consists of two chambers: the first is devoted to settling, and the second serves as a filter bed consisting of sand or an organic filter media. Because they consume very little surface land area and have few site restrictions, stormwater filters are a versatile option that offers moderate pollutant removal performance at small sites where space is limited. The water quality treatment process employed by filtering practices are settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, and plant uptake (biological transformation) or removal by bacteria.



Figure 8.32. Sand Filter



Figure 8.33. Bioretention Filter Cell

2. **Bioretention (#9) (Figure 8.33).** Individual bioretention areas serve highly impervious drainage areas less than five acres in size. Surface runoff is directed into a shallow landscaped depression that incorporates many of the pollutant removal mechanisms that operate in forested ecosystems. The primary component of a bioretention practice is the filter bed, which has a mixture of sand, soil, and organic material as the filtering media. The filter is composed of a sand/soil bed with a surface layer of mulch. During storms, runoff temporarily ponds 6-12 inches above the mulch layer and then rapidly filters through the bed.

Normally, the filtered runoff is collected in an underdrain and returned to the storm drain system. The underdrain consists of a perforated pipe in a gravel jacket installed along the bottom of the filter bed. Bioretention creates a good environment for runoff reduction, filtration, biological uptake, and microbial activity, and provides high pollutant removal. Bioretention can become an attractive landscaping feature with high amenity value and community acceptance. The water quality treatment processes employed by dry swales are runoff volume reduction, settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, separation from solution (precipitation) onto the media, and plant uptake (biological transformation) or removal by bacteria.

8.2.2.4. Infiltration Practices

The following practices capture and temporarily store the T_v before allowing it to infiltrate into the B and/or C soil horizons. Runoff that discharges directly into limestone (karst) areas may be treated by certain kinds of infiltration practices (e.g., small-scale infiltration, permeable pavers and, perhaps, micro-bioretention/rain gardens).

1. **Permeable Pavement (#7) (Figures 8.34 and 35).** Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir where it is temporarily stored. Often, the filtered runoff is collected in an underdrain and returned to the storm drain system. If infiltration rates in native soils permit, permeable pavement practices can be designed without an underdrain for

full infiltration. A combination of these methods can be used to infiltrate a portion of the filtered runoff.



Figure 8.34. Permeable Asphalt Pavement



Figure 8.35. Permeable Interlocking Pavers

There are a variety of permeable pavement surfaces available in the commercial marketplace, including pervious concrete, porous asphalt, permeable interlocking concrete pavers, concrete grid pavers, and plastic grid pavers. While the specific design configuration may vary according to each product, nearly all permeable pavement types have the same general structure, consisting of a surface layer, aggregate base, and sub-base. The aggregate base layer serves to retain stormwater and also supports the design traffic loads. Permeable pavements are typically designed to treat rainfall on the pavement surface area, but can also be used to treat run-on from small adjacent impervious areas, such as impermeable driving lanes or rooftops.

Permeable pavements promote runoff reduction and provide high pollutant removal. Permeable pavement can also be used to reduce the impervious cover of a development site. The water quality treatment process employed by permeable paving materials is mainly runoff volume reduction. Pre-treatment must be provided to remove sediment, which would otherwise clog the pores in the paving material. A filter fabric is typically installed beneath the aggregate base, as well. So little or no treatment (filtering, etc.) is provided within the structure.

2. ***Infiltration Practices (#8) (Figure 8.36 below).*** Infiltration practices utilize temporary surface or underground storage to allow incoming stormwater runoff to exfiltrate into underlying soils. Runoff first passes through multiple pretreatment mechanisms to trap sediment and organic matter before it reaches the practice. As the stormwater penetrates the underlying soil, water quality treatment processes such as chemical adsorption (sorption, precipitation) and biological transformation processes remove pollutants. Infiltration practices are suitable for use in residential and other urban areas where *measured* soil permeability rates exceed 0.5 inch per hour. Infiltration is not recommended at sites designated as stormwater hotspots, to prevent possible groundwater contamination.

Infiltration has the highest runoff reduction capability of any stormwater practice, and probably comes closest to replicating predevelopment hydrology. On the other hand,

infiltration practices have experienced consistent problems and failures over the years. These anecdotal reports, along with groundwater concerns, have limited the use of infiltration practices. Toward this end, the Department, with assistance from the Chesapeake Stormwater Network and the Center for Watershed protection, has prepared a new infiltration practice design specification that should result in more widespread use of infiltration and better water quality protection and runoff management, while minimizing the risk of failure.



Figure 8.36. Infiltration Trench Construction



Figure 8.37. Bioinfiltration Cell

3. **Bioinfiltration (#9) (Figure 8.37):** Bioinfiltration (Level 2 Bioretention and Level 2 Dry Swale) can also be designed to infiltrate runoff into native soils. This can be done at sites with highly permeable soils, a low groundwater table, and a low risk of groundwater contamination. This type of design features the use of a “partial exfiltration” system that promotes greater groundwater recharge. Underdrains are only installed beneath a portion of the filter bed or are eliminated altogether, thereby increasing stormwater infiltration. Bioretention is also known as a “rain garden” when used on individual residential lots, often without an underdrain. The water quality treatment processes employed by Bioinfiltration are runoff volume reduction, settling (sedimentation), filtering (filtration), adherence (sorption) to the soil, separation from solution (precipitation) onto the soil, and plant uptake (biological transformation) or removal by bacteria.

8.2.2.5. Basins (Ponds and Wetlands)

Practices that have one or more permanent pools capable of treating the Treatment Volume (T_v) and may incorporate extended detention or significant shallow marsh areas. Basins are the final element in the roof-to-stream runoff reduction sequence. However, they should only be considered after all other upland runoff reduction techniques have been exhausted, and there is still a remaining water quality or channel protection volume to manage.

1. **Constructed Wetlands (#13) (Figure 8.38).** Constructed Wetlands are shallow depressions that receive stormwater inputs for treatment. Wetlands are typically less than one foot deep (although they have deeper pools at the forebay and micropool) and possess variable microtopography to promote dense and diverse wetland cover. Runoff from each new storm displaces runoff from previous storms, and the long residence time allows multiple pollutant removal processes to operate. The wetland environment provides an ideal environment for gravitational settling, biological uptake, and microbial activity. The water quality treatment processes exhibited by constructed wetlands are settling (sedimentation), flotation of light solids, adherence (sorption) to bottom soils, chemical separation from solution (precipitation) in the water, and biological transformation by bacteria and plant uptake.



Figure 8.38. Constructed Wetland



Figure 8.39. Small Wet Pond

2. **Wet Ponds (#14) (Figure 8.39).** Wet Ponds consist of a permanent pool of standing water that promotes a better environment for gravitational settling, biological uptake, and microbial activity. Runoff from each new storm enters the pond and partially displaces pool water from previous storms. The pool also acts as a barrier to re-suspension of sediments and other pollutants deposited during earlier storms. When sized properly, Wet Ponds have a residence time that ranges from many days to several weeks, which allows numerous pollutant removal mechanisms to operate. Wet Ponds can also provide extended detention (ED) above the permanent pool to help meet channel protection requirements. The water quality treatment processes exhibited by Wet Ponds are settling (sedimentation), flotation of light solids, adherence (sorption) to bottom soils, chemical separation from solution (precipitation) in the water, and biological transformation free floating algae.
3. **Extended Detention (#15) (Figure 8.40 below).** Extended Detention (ED) ponds rely on gravitational settling as their primary pollutant removal mechanism. Consequently, they generally provide fair to good removal of particulate pollutants but low or negligible removal for soluble pollutants, such as nitrate and soluble phosphorus. Extended Detention is different from stormwater detention, which is used for peak discharge or flood control purposes and often detains flows for just a few minutes or hours. This option relies on 12 to 24 hour detention of stormwater runoff after each rain event. An under-sized outlet structure restricts stormwater flow so it backs up and is stored within a pond or wetland. The temporary ponding enables particulate pollutants to settle and reduces stress on downstream banks. The use of ED alone generally has the lowest overall pollutant removal rate of any stormwater

treatment option. As a result, ED is normally combined with wet ponds or constructed wetlands to maximize pollutant removal rates. The water quality treatment process exhibited by extended detention basins is mainly settling (sedimentation).



Figure 8.40. Dry Extended Detention Basin

8.2.2.6. Manufactured Treatment Devices (MTDs) (*Figures 8.41 and 8.42*)

Virginia allows the use of certain Manufactured Treatment Devices (MTDs) for which pollution removal performance has been verified and certified through by the Virginia Stormwater BMP Clearinghouse Committee and the DEQ. There is a wide variety of products within this category, which provides different kinds of stormwater management options, ranging from underground detention storage to flow control to filtering technologies.

8.2.2.7. Treatment Trains

BMPs suitable to meet channel protection and overbank flood criteria should not be used by themselves to also address water quality requirements but should, instead, be combined in a “treatment train” with one or more other BMPs to meet water quality requirements. Pre-treatment BMPs are designed to improve water quality and enhance the effective design life of practices by consolidating sedimentation location, but they also cannot meet the water quality requirements by themselves. Pre-treatment practices must be combined with other water quality BMPs to meet the water quality criteria. It is important that the various BMPs employed in a treatment train should use *different* treatment mechanisms in order to maximize pollution removal (e.g., rooftop disconnection to a grass channel to biofilters and bioretention to a constructed wetland, as depicted in **Figure 8.41** below).

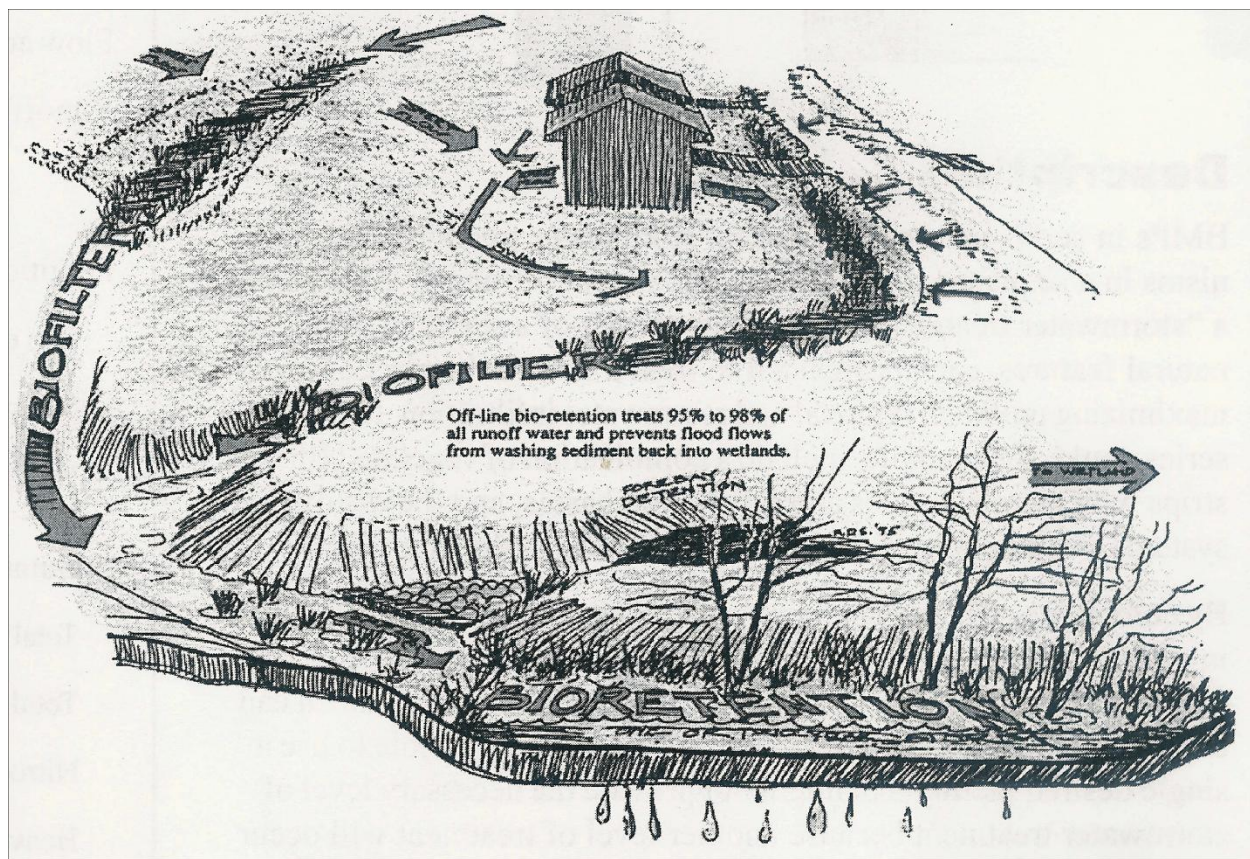


Figure 8.41. Treatment Train

Source: Robert Sykes, Dept. of Landscape Architecture, University of Minnesota

8.3. POST-CONSTRUCTION BMP DESIGN & CONSTRUCTION STANDARDS AND SPECIFICATIONS

Complete standards and specifications for Virginia-approved post-construction BMPs and MTDs can be found on the Virginia BMP Clearinghouse web site, at <http://www.vwrrc.vt.edu/swc/>. For each public domain BMP, criteria are provided to address the following topics:

Description: Describes the practice and explains its purpose and how it functions.

Performance: Identifies how well the practice addresses various objectives of stormwater management.

- Runoff Reduction (which includes Groundwater Recharge)
- Total Phosphorus Removal
- Total Nitrogen Removal
- Total Suspended Solids (TSS) Removal
- Channel Protection
- Flood Mitigation

Design Table: Identifies the sizing criteria for the practice needed to accommodate the full T_v and geotechnical or other testing that must be done to provide information needed to correctly design the facility.

Typical Graphical Details: Provides visual guidance regarding how to correctly design and build the particular practice.

Physical Feasibility and Design Applications: Identifies site considerations and physical constraints that determine where a practice may be applied or that may restrict the use of a practice.

Design Criteria: Identifies the specific standards and specifications that govern the correct design of specific devices, including dimensions, components, orientation, etc. The design criteria include but is not limited to information about the following:

- **Pretreatment:** Identifies the type of measures used to trap coarse elements before they enter the facility, thus reducing the maintenance burden and ensuring a long-lived practice.
- **Conveyance:** Identifies how to convey runoff to the practice in a manner that is safe, minimizes erosion and disruption to natural channels, and promotes filtering and infiltration.
- **Geometry:** Identifies any practice-specific configurations, such as optimum length-to-width-to-depth ratios, minimum flow lengths, etc.
- **Material Specifications:** Identifies the specific kinds of materials (e.g., stone sizes, landscaping materials, etc.) needed to correctly construct the particular practice.
- **Environmental/Landscaping:** Identifies how to reduce secondary environmental impacts of facilities through features that minimize disturbance of natural stream systems and comply with environmental regulations. Provides landscaping that enhances the pollutant removal and aesthetic value of the practice.
- **Maintenance Considerations for the Design:** Identifies the design elements that ease the maintenance burden.

Regional and Climate Design Adaptations: Identifies considerations and adaptations needed to address particular kinds of regional characteristics or climate variations, including the following:

- Hot spots
- Ultra-Urban Development Sites
- Infill and Redevelopment Sites
- Single-Family Lots
- Karst terrain
- Coastal plain
- Steep terrain
- Sensitive Waters
 - Lakes and Water Supply Reservoirs
 - Trout and Other High-Quality Streams
 - Groundwater Drinking Water Source Areas
 - Wetlands
 - Impaired Waters

- Cold climates/winter performance
- Linear/highway sites

Construction Sequence and Inspection: Identifies factors important to the proper construction and long-term viability of the particular practice.

Maintenance: How to maintain the long-term performance of the practice through regular maintenance activities.

Community and Environmental Considerations: Addresses issues such as physical safety, potential for vectors, aesthetics, etc.

References: A list of resources from which the criteria and information in the design specification were taken.

Overviews of the public domain post-construction BMPs that DEQ has approved for use in Virginia can be found in Section 8.4.2 (above) of this chapter.

8.4 BMP SELECTION CATEGORY DESCRIPTIONS AND TABLES

8.4.1 Land Use (Table 8.3 below)

Which practices are best suited for the proposed land use at this site? In this step, the designer makes an initial screening to select practices that are best suited to a particular land use.

Rural. This column identifies BMPs that are best suited to treat runoff in rural or very low density areas (e.g., typically at a density of less than ½ dwelling unit per acre) with few neighborhoods and relatively large amounts of open space. Stormwater control measures with larger area demands may be easier to locate with appropriate buffers in rural areas. Additionally, typical stormwater pollutants from rural areas include sediments and nutrients, which can be effectively managed by most stormwater control measures. As a result, most BMPs are suitable for rural areas.

Residential. This column identifies the best treatment options in medium to high density residential developments, which typically have limited space and higher property values compared to rural undeveloped land. Also, stormwater control measures in residential areas are likely to be located in close proximity to residences. Public safety and nuisance insects are common concerns related to control measures in residential areas. BMPs with large land requirements or open pools of water may be less desirable in these areas. In some situations, stormwater ponds or other open water practices may be incorporated into the landscape as amenities to provide for habitat, recreation, and aesthetic value.

Roads and Highways. This column identifies the best practices to treat runoff from major roadway and highway systems, which typically generate high stormwater pollutant loads due to vehicle traffic and winter deicing activities. Sediments, metals, chlorides, and hydrocarbons are the primary pollutants associated with roads and highways. Nitrogen from vehicle exhausts and

bacteria are also commonly present in road and highway runoff. As a result, most treatment practices provide some treatment benefit but do not adequately address all of the water quality impacts associated with this land use. In addition, open water and deep pools can also be a safety issue near roads and highways.

Commercial/Industrial Development. This column identifies practices that are suitable for commercial and industrial development, which often have more intensive traffic, increased risk of spills, and exposure of materials to precipitation. Pollutants associated with these land uses can vary significantly, depending on the nature of activities at each site, although traffic-related pollutants such as sediments, metals, and hydrocarbons are commonly present in runoff from most commercial and industrial sites. These developments may also have more available space for locating stormwater control measures.

Hotspot Land Uses. This column examines the capability of BMPs to treat runoff from designated hotspots. BMPs that receive hotspot runoff may have design restrictions, as noted.

Ultra-Urban Sites. This column identifies BMPs that work well in the ultra-urban environment, where population is dense, land area and space are limited, stormwater infrastructure is already in place, a wide range of potential pollutants is present, and original soils have been disturbed. Ultra-urban sites are the most restrictive in terms of BMP selection. Stormwater control measures appropriate for ultra-urban sites are also frequently used at redevelopment and infill sites and to retrofit existing urban development.

Table 8.3. BMP Selection Matrix 1 – Land Use

BMP Group	Specific BMP	Rural	Residential	Roads and Highways	Commercial/Industrial	Hotspots	Ultra-Urban ¹
Runoff Volume Reduction	Rooftop Disconnection 1	○	○	●	○	○	◐
	Sheet flow to Veg. Filter/Open Space	○	○	○	○	◐ ²	◐
	Soil Compost Amendments	○	○	○	○	◐ ²	○
	Vegetated Roof	●	◐	●	○	○	○
	Rainwater Harvesting	○	○	●	○	○ ³	○
Swales & Open Channels	Grass Channel	○	◐	○	◐	◐ ⁴	◐
	Dry Swale	○	◐	○	◐	◐ ⁴	●
Filtering Systems	Bioretention 1	◐	◐	○	○	○ ⁴	○ ¹
	Filtering Practice	●	●	○	○	○ ⁵	○
Infiltration Practices	Permeable Pavement	◐	◐	●	◐	●	○
	Infiltration	◐	◐	○	○	●	◐
	Urban Bioretention	◐	◐	○	○	○ ² (Needs underdrain)	○
	Bioretention 2	◐	◐	○	○	○ ² (Needs underdrain)	○
Basins	Wet Swale	○	○	○	●	◐	●
	Constructed Wetland	○	○	○	◐	◐ ²	●
	Wet Pond	○	○	○	◐	◐ ⁵	●
	Extended Detention	○	○	○	◐	◐ ⁵	●
Mfr Treatment Devices	Hydrodynamic Devices	●	○	○	○	●	○
	Filtration Devices	●	○	○	○	◐	○
	Storage Devices	●	●	●	○	◐ ^{2,4}	○
<p>○ Appropriate. Good option in most cases.</p> <p>◐ Depends. Suitable under certain conditions, or may be used to treat a portion of the site.</p> <p>● Least appropriate. Seldom or never suitable.</p> <p>¹ Secondary treatment practices and stormwater treatment trains are typically more appropriate for Ultra-Urban land uses</p> <p>² Not allowed unless pretreatment provided to remove hydrocarbons, trace metals, and toxicants</p> <p>³ Unless the roof is considered a hotspot</p> <p>⁴ Acceptable option, if <u>not</u> designed as an exfilter. (An exfilter is a conventional stormwater filter without an underdrain system. The filtered volume ultimately infiltrates into the underlying soils.)</p> <p>⁵ Acceptable option, but may require an impermeable liner to reduce risk of groundwater contamination.</p>							

8.4.2 Physical Feasibility (Table 8.4 below)

Are there any physical constraints at the project site that may restrict or preclude the use of a particular BMP? In this step, the designer screens the various BMP design criteria to determine if the soils, water table, drainage area, slope or head conditions present at a particular development site might limit the use of a BMP. More detailed testing protocols are often needed to confirm physical conditions at the site. The following are the primary factors.

Soil Infiltration Rate. The key evaluation factors are based on an initial investigation of the NRCS Hydrologic Soil Groups at the site. Note that more detailed geotechnical tests are usually required for infiltration feasibility and during design to confirm permeability and other factors. Knowledge of all soil groups present on the site is needed for runoff calculations, but the presence of HSG-A or HSG-D soils are most likely to constrain the choice of certain BMPs.

Water Table Separation. This column indicates the minimum depth to the seasonally high water table from the bottom elevation, or floor, of a BMP. A relatively shallow depth to water table may limit the choice of certain BMPs.

Shallow Soils/Depth to Bedrock. Likewise, this column indicates the minimum depth to bedrock from the bottom elevation, or floor, of a BMP. A relatively shallow depth to bedrock may also limit the choice of certain BMPs.

Contributing Drainage Area. This column indicates the minimum or maximum drainage area that is considered optimal for a practice. If the drainage area present at a site is slightly greater than the maximum allowable drainage area for a practice, some leeway is warranted where a practice meets other management objectives. Likewise, the minimum drainage areas indicated for ponds and wetlands should not be considered inflexible limits, and may be increased or decreased depending on water availability (base flow or groundwater), mechanisms employed to prevent clogging, or the ability to assume an increased maintenance burden.

Slope. This column evaluates the effect of slope on the practice. Specifically, the slope guidance refers to how flat the area where the practice is installed must be and/or how steep the contributing drainage area or flow length can be.

Hydraulic Head. This column provides an estimate of the elevation difference needed for a practice (from the inflow to the outflow) to allow for gravity operation.

Karst Geology. This column provides information regarding the appropriateness of the various BMPs for installation in karst environments and conditions that apply to those BMPs in such areas. Karst is a dynamic landscape formed over the millenia by the dissolution of bedrock such as limestone, dolomite, and marble. Karst is characterized by landscape features such sinkholes, springs, caves, a highly irregular soil-rock interface, and typically a poorly defined surface drainage network. Karst terrain is considered to be any landscape underlain by carbonate bedrock in the shallow subsurface or any area expressing characteristic karst features. Karst poses many challenges to BMP selection and design. Many sinkholes form due to the collapse of the surface sediments caused by the intrusion of stormwater from the surface. Some BMPs inadvertently

promote sinkhole formation that may threaten the integrity of the practice as well as structures on the site. In addition, Karst geology provides rapid pathways for water to travel from the surface to deep groundwater and aquifers, so it should be assumed that any treated or untreated runoff that is infiltrated will reach the drinking water supply in karst areas.

Table 8.4. BMP Selection Matrix 2 – Physical Feasibility

BMP Group	Specific BMP	Soils ¹	Water Table Separation	Depth to Bedrock/Shallow Soils	Contrib. Drainage Area (Ac.)	Max. Site Slope ²	Hydraulic Head (Ft.)	Karst Geology or a Sinkhole	Cold Climate (cf Table 8.5)
Runoff Volume Reduction	Rooftop Disconnect.	Join with additional runoff reduction practice on C-D soils	2 feet	2 feet	Maximum 1,000 sq. ft. to each roof discharge point	1-2%	1 foot	Preferred	Frozen ground may hinder disposal of water
	Sheet flow to Vegetated Filter or Conserved Open Space	Any soil except fill; best to use w/ compost amend's on C-D soils	2 feet	2 feet	3 max.	6% for consrv filter; 8% for grass filter strip	1 to 2 feet	Preferred	No concerns or needed adaptations
	Soil Compost Amendments	HSG B-D soils	1.5 feet	1.5 feet	Contrib. Imperv. area should not exceed area of amended soil	10%	1 foot	OK	OK, except for areas used for snow storage
	Vegetated Roof	NA	NA	NA	NA	NA	1 to 2 feet	Preferred	Plan for snow loading and hardy veg. cover
	Rainwater Harvesting	NA	Below-grade tanks must be above water table	Below-grade tanks must be above bedrock	Rooftop (only) area draining to the tank	NA	Varies with purpose and design	Preferred	Locate indoors or underground; others should be operated seasonally
Swales & Open Channels	Grass Channel	Must achieve additional res. time (min. 10 minutes) if C-D soils	2 feet	2 feet	5 max.	2-4%	2 to 3 feet	OK ³	OK
	Dry Swale	Made Soil; must use underdrain if on C-D soils	2 feet	2 feet	5 max.	4%	3 to 5 feet	Prefer'd ³	Medium benefit & limitation

BMP Group	Specific BMP	Soils ¹	Water Table Separation	Depth to Bedrock/ Shallow Soils	Contrib. Drainage Area (Ac.)	Max. Site Slope ²	Hydraulic Head (Ft.)	Karst Geology or a Sinkhole	Cold Climate (cf Table 8.5)		
Filtering Systems	Filtering Practice	NA	2 feet	2 feet	5 max. ⁴ ; 0.5 to 2 preferred	NA	2 to 10 feet	Prefer'd, but must use impermeable liner	OK if place below frost line and use pretreatment; Chlorides will move through untreated		
	Bioretention 1 (with underdrain)	Made Soil	2 feet	2 feet	5 max. ⁴ ; 0.5 to 2 preferred	1-5%	4 to 5 feet	OK, but must use underdrain and impermeable liner	OK; use salt-tolerant veg. and pretreatment; Chlorides will move through untreated		
Infiltration Practices	Permeable Pavement 1	Must use underdrain on C-D soils	2 feet	2 feet	Ratio of contrib. pavement area to Permeable Pavement area may not exceed 2:1	1-3%	2 to 4 feet	Large-scale or Level 2 Prohibited; Small-scale OK; must have liner and underdrain; extensive pre-treatment required	Limited; Use special design features; Active mgmt needed to prevent infiltration of chlorides and soluble toxics		
	Permeable Pavement 2	Minimum measured f _c > 0.5 inch/hour			< 2, and close to 100% impervious	0-5%	2 to 4 feet				
	Infiltration	Minimum measured f _c > 0.5 inch/hour									
		Urban Bioretention	NA	2 feet	2 feet	5 max. ⁴ ; 0.5 to 2 preferred	1-5%	4 to 5 feet	Preferred	OK; use salt-tolerant veg. and pretreatment; Chlorides will move through untreated	
		Bioretention 2 (Bioinfiltration, with no underdrain)	Made Soil; use underdrain if C or D ³ base soils	3 feet	2 feet	5 max. ⁴ ; 0.5 to 2 preferred	1-5%	4 to 5 feet	Not Recmd, esp. large scale; extensive pre-treatment required	OK; use salt-tolerant veg. and pretreatment; Chlorides will move through untreated	

BMP Group	Specific BMP	Soils ¹	Water Table Separation	Depth to Bedrock/Shallow Soils	Contrib. Drainage Area (Ac.)	Max. Site Slope ²	Hydraulic Head (Ft.)	Karst Geology or a Sinkhole	Cold Climate (cf Table 8.5)
Basins	Wet Swale	Best on HSG C or D soils	Below water table	2 feet below bottom of swale	5 max..	2% thru swale	2 feet	Not Recmd	Medium benefit & limitation
	Constructed Wetland	HSG-A or B soils may require liner	Below water table if no hotspot or aquifer present; otherwise, a 2 foot separation	2 feet below bottom of wetland	25 min. ⁶	NA	2 to 4 feet	OK; use impermeable liner; limit depth; geotech. tests needed; max. ponding depth	OK; use salt-tolerant vegetation
	Wet Pond	HSG-A or B soils may require liner	Below water table if no hotspot or aquifer present; otherwise, a 2 foot separation	2 feet below bottom of wetland	25 min. ⁵	NA	6 to 8 feet	Not Recmd ⁶	OK; limit depth to avoid stratification; adapt outlet structure
	Extended Detention 1	HSG-A or B soils may require liner	2 feet	2 feet	< 10	NA	6 to 10 feet	Not Recmd ⁶	OK
	Extended Detention 2				> 10				
Mfr Treatment Devices	Hydrodynamic Devices	NA	Varies with device; Must have clearance below bottom of device	Varies with device; Must have clearance below bottom of device	?	NA	?	OK	?
	Filtration Devices	NA			?	NA	?	OK	?
	Storage Devices	NA			?	NA	?	Must have liner and under-drain; Significant pre-treatment required	?

KEY: OK = not restricted; WT = water table; PT = pretreatment; f_c = soil permeability

¹ USDA-NRCS Hydrologic Soil Groups (HSGs)

² Refers to post-construction slope across the location of the practice

³ Denotes a required limit, other elements are planning level guidance and may vary somewhat, depending on site conditions

⁴ Drainage area can be larger in some instances.

⁵ 10 acres may be feasible if ground water is intercepted and/or if water balance calculations indicate a wet pool can be sustained, and an anti-clogging device must be installed

⁶ If detention is used, then an impermeable liner must be placed at the bottom of the basin and geotechnical tests should be conducted to determine the maximum allowable depth

Cold Climate/Winter Conditions. This column presents guidance on how to choose BMPs for areas of Virginia where much colder temperatures, greater snowfall, and more ice prevail. While there may be fewer runoff events during winter months, snow and ice may significantly impact the operation of some BMPs during winter rain events and periods of snowmelt. Some of these

potential impacts are (1) pipe freezing, (2) ice formation on permanent pools, (3) reduced biological activity, and (4) reduced soil infiltration. Frozen conditions typically inhibit performance throughout the winter and generate a significant volume of melt water and associated pollutant loads. In particular, melt water from roadways typically has high chloride and sediment content from salt and sand treatments. **Table 8.5** summarizes winter operation and cold weather considerations for various stormwater treatment practices.

Table 8.5. BMP Selection Matrix 3 – Winter and Cold Weather Stormwater Control Operational Criteria

Category	Practice	Pipe Freezing	Ice Formation	Reduced Biological Activity	Reduced Soil Infiltration
Ponds	Wet Ponds	●	●	◐	○
	Extended Detention Ponds	●	●	◐	○
	Vegetated Roofs	●	◐	○	○
Wetlands	Constructed Wetlands	●	●	●	○
	Wet Swales	○	◐	◐	○
Infiltration	Level 1 Infiltration	◐	◐	○	●
	Level 2 Infiltration	○	◐	○	●
	Level 2 Bioretention	○	◐	○	●
	Level 2 Dry Swale	○	◐	◐	◐
	Permeable Pavement	◐	●	○	●
Filters	Surface Filtering Practices	◐	◐	○	●
	Underground Filtering Practices	○	○	○	○
	Level 1 Bioretention	◐	◐	○	●
	Level 1 Dry Swale	◐	◐	○	●
	Sheet flow to Vegetated Filter or Conserved Open Space	○	◐	○	◐
Key: ● = Significant ◐ = Moderately Significant ○ = Least Significant					

8.4.3 Critical Water Resources (Table 8.6 below)

What watershed protection goals need to be met in the water resources the site drains to? The design and implementation of BMPs is strongly influenced by the nature and sensitivity of the receiving waters. In some cases higher pollutant removal, more recharge or other environmental performance is warranted to fully protect the resource quality and human health and/or safety. Critical resource areas include: *groundwater and source water areas, high value trout streams, other freshwater streams, freshwater lakes and ponds, drinking water reservoirs, freshwater wetlands, and coastal waters (including tidal wetlands)*, as described below. **Table 8.6** below outlines the key design variables and considerations that must be addressed for sites that drain to any of the above critical resource areas.

Table 8.6. BMP Selection Matrix 4 – Critical Water/Watershed Resources

BMP Group	Specific BMP	Groundwater, Source Water Areas and Septic Systems	100-Year Flood Plains	Trout and Other Freshwater Streams	Freshwater Lakes and Ponds	Freshwater Wetlands (May be regulated)	Coastal Waters (incl. Tidal Wetlands)	Impaired Waters
General Location		Setbacks from wells and septic systems	Restrict grading & fill; no raising 100-year water surface elevation	Outside the stream buffer, where required or otherwise established	Outside of shoreline buffer, where required or otherwise established	Outside of wetland buffer, where required or otherwise established	Outside of wetland buffer, where required or otherwise established	Selection based on Pollutant Removal for Target Pollutant
Runoff Volume Reduction	Rooftop Disconnect.	OK	OK	Preferred; best if used with suppl. practices	OK	OK	Preferred	OK; best if used with suppl. practices
	Sheet flow to Vegetated Filter or Conserved Open Space	OK	OK	Preferred	OK	Does NOT apply to jurisdictional wetlands	Preferred	OK
	Soil Compost Amendments	OK	OK	Preferred	OK	OK	OK	OK
	Vegetated Roof	NA	NA	OK	NA	NA	OK	NA
	Rainwater Harvesting	OK ¹	OK	Preferred	OK	OK	Preferred	OK
Swales & Open Channels	Grass Channels	Pre-treat hotspots prior to discharge to channel or swale	OK	Preferred; link w/ other BMPs to protect channel and prevent flooding	OK; dry swale provides the best TP removal	OK, dry swale provides the best TP removal	Restricted (poor bacteria removal)	OK
	Dry Swales						Preferred	
Filtering Systems	Filtering Practices	OK – a Preferred practice		Preferred, but link w/ other BMPs to protect channel and prevent flooding	OK -- get moderate to high TP removal	OK, moderate to high TP removal	OK, moderate to high bacteria and TN removal	Preferred practices
	Bioretention 1	OK, with cautions for PSHs		Preferred practice	Preferred practice	Preferred practice	Preferred; mod to high bacteria and TN removal	
Infiltration Practices	Permeable Pavement	100 foot SD from water supply wells; pre-treat runoff in limestone regions; Restricted, if site is a PSH; may need injection well permit	Use only practices with impermeable liners and under-drains	Preferred if site has appropriate soils	Preferred, if site has appropriate soils, in which case these are preferred practices	Preferred, if site has appropriate soils	Preferred	Restricted for some target pollutants
	Infiltration						Lg. scale OK; small scale restricted	
	Urban Bioretention			Extremely limited feasibility			OK	
	Bioretention 2			Preferred if site has appropriate soils			Preferred; mod to high bacteria and TN removal	

BMP Group	Specific BMP	Groundwater, Source Water Areas and Septic Systems	100-Year Flood Plains	Trout and Other Freshwater Streams	Freshwater Lakes and Ponds	Freshwater Wetlands (May be regulated)	Coastal Waters (incl. Tidal Wetlands)	Impaired Waters
Basins Basins	Wet Swales	Preferred practice	OK	OK, but use only shaded swales near trout streams	OK	Preferred practice	Preferred	Preferred practice
	Constructed Wetlands	Preferred practice	OK	OK, but use only wooded wetlands near trout streams	Some designs restricted due to seasonally variable P removal, combined with other treatments	Preferred practice, but no use of existing natural wetlands	Preferred	Preferred practice
	Wet Ponds	Pre-treat hotspots; provide a 2 foot SD from seasonal high groundwater elevation	May not locate ponds in the flood plain	Restricted due to pool and stream warming concerns; overland erosion and channel protection is necessary	Design for enhance TP removal; use ponds with wetlands for best TP removal	Design for enhance TP removal; use ponds with constr. (NOT natural) wetlands for best TP removal	OK; Moderate bacteria removal; good to moderate TN removal; max. normal pool depth of 4 feet; Provide long ED (> 48 hrs) for max. bacteria die-off	Preferred practice
	Extended Detention	Does not meet Treatment Volume pre-treatment requirements	May not locate ponds in the flood plain	Not recm'd near trout streams unless need to provide for channel protection and flood protection; then use special design; Not recm'd within stream	Generally not necessary if discharge is directly to a large lake	Not recm'd within natural wetlands, nor should they inundate or otherwise change the wetland's hydroperiod	Restricted (limited feasibility)	May be restricted if warming is part of impairment
Mfr Treatment Devices	Hydrodynamic Devices	OK	May not locate in the flood plain	?	OK	?	OK	?
	Filtration Devices			?		?		?
	Storage Devices			?		?		?

NOTES: SD = separation distance; ED = extended detention PSH = potential stormwater hotspot

¹ This is a matter of the scale of the use of rainwater harvesting; if sufficient water is diverted for recycling, a nearby aquifer may be deprived of recharge water.

8.4.4 Stormwater Management Capability (Table 8.7 below)

Can one BMP meet all design criteria, or is a combination of practices needed? In this step, designers can screen the BMP list to determine if a particular BMP can meet each of the SWM criteria: *water quality, groundwater recharge, receiving channel/overland flow protection, and flood control* storage requirements. At the end of this step, the designer can screen the BMP options down to a manageable number and determine if a single BMP or a group of BMPs (e.g., a treatment train) are needed to meet stormwater sizing criteria at the site.

Water Quality Treatment. This column indicates whether each practice can be used to provide for effective water quality treatment (i.e., pollutant removal). For more detail on specific pollutant removal, consult **Table 8.8** below.

Runoff Volume Reduction. This column indicates whether each practice can provide for a reduction of runoff volume from the site, which contributes to pollutant removal and may contribute to groundwater recharge, depending on the specific practice. Obviously, the more runoff can be reduced in ways that keep it on the development site, the less runoff will be discharged from the site.

Groundwater Recharge. This column indicates whether each practice can provide for groundwater recharge. It may also be possible to accomplish some groundwater recharge by using Environmental Site Design techniques (see **Chapter 6**).

Receiving Channel/Overland Flow Protection. This column indicates whether the BMP can typically provide for the channel protection storage volume. The finding that a particular BMP cannot meet the channel protection requirement does not necessarily imply that the BMP should be eliminated from consideration, but is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream extended detention pond).

Flood Control. This column indicates whether a BMP can typically meet the overbank and extreme flood control criteria for the site. Again, the finding that a particular BMP cannot meet the channel protection requirement does not necessarily imply that the BMP should be eliminated from consideration, but is a reminder that more than one practice may be needed at a site (e.g., a bioretention area and a downstream extended detention pond).

8.4.5 Pollutant Removal

How do each of the BMP options compare in terms of pollutant removal? In this step, the designer views removal of select pollutants to determine the best BMP options for water quality. It is important to note that the Total Pollutant Reductions (TR) indicated in **Table 8.8** below for TP, TN, and TSS reflect a combination of pollutant removal processes. These numbers assume a typical concentration for each pollutant in the total site runoff. These concentrations are typically expressed as an amount per unit of volume (e.g., 0.26 mg/L of TP). When part of the total runoff volume is removed through the use of Runoff Reduction practices (e.g., rainwater capture, infiltration, etc.), the pollutants in that removed volume are removed from the remaining runoff that must still be managed. Then, as Stormwater Treatment processes (e.g., settling, filtration,

chemical conversion, vegetation uptake, etc.) are applied to that remaining runoff, the actual concentration of pollutant in the runoff is further reduced. So the total mass load removal of pollutants is a result of the combination of runoff volume reduction and supplementary treatment practices. **Table 8.8** examines the capability of each BMP option to remove specific pollutants from stormwater runoff.

Table 8.7. BMP Selection Matrix 5 – Stormwater Management Capability

BMP Group	Specific BMP	Water Qual. Treatment	Runoff Volume Reduction	Groundwater Recharge	Channel/Overland Flow Protection	Flood Control
Runoff Volume Reduction	Vegetated Roof	●	○	●	◐ ⁴	●
	Rooftop Disconnection	●	○	●	◐ ⁴	●
	Rainwater Harvesting	●	○	●	◐ ⁴	●
	Soil Compost Amendments	●	○	◐	◐ ⁴	●
	Sheet flow to Vegetated Filter or Conserved Open Space	●	◐	◐	●	●
Swales & Open Channels	Grass Channel	○	○	○	●	●
	Dry Swale	○	○	○ ¹	◐ ⁴	●
Filtering Systems	Filtering Practice	○	●	●	●	●
	Bioretention 1	○	○	○ ¹	◐ ⁴	●
Infiltration Practices	Permeable Pavement 1	○	○	◐	◐ ⁴	○ ²
	Permeable Pavement 2	○	○	○	◐ ⁴	○ ²
	Infiltration	○	○	○	◐ ⁴	○ ²
	Bioretention 2	○	○	○	○	○ ²
Basins	Constructed Wetland	○	○	○ ³	○	○
	Wet Swale 1	○	◐	●	●	●
	Wet Swale 2	○	●	●	●	●
	Wet Pond	○	○	○	○	○
	Extended Detention 1	●	●	●	○	○
	Extended Detention 2	◐	◐	◐	○	○
Mfr Treatment Devices	Hydrodynamic Devices	Varies	●	●	●	●
	Filtration Devices	Varies	Varies	●	●	●
	Storage Devices	●	○	Varies	Varies	Varies
<p>○ Practice generally meets this stormwater management goal.</p> <p>◐ Practice may partially meet this goal, or under specific site and design conditions</p> <p>● Practice can almost never be used to meet this goal.</p> <p>¹ Provides recharge only if designed as an exfilter system.</p> <p>² Can be used to meet flood control in rare conditions, with very cobbly or highly permeable soils.</p> <p>³ Yes, unless impermeable liners are required or the pool intercepts groundwater</p> <p>⁴ By removing/infiltrating water, thus reducing the overall volume of runoff</p>						

Table 8.8. BMP Pollutant Removal Efficiencies

Practice	Runoff Volume Reduc. ¹ (%RR)	TP EMC Reduc. ² (%PR)	Total TP Reduc. ³ (%TR)	TN EMC Reduc. ² (%PR)	Total TN Reduc. ³ (%TR)	TSS EMC Reduc. ² (%PR)	Total TSS Reduc. ³ (%TR)	Total Bacteria Reduc. ^{3, 4} (%TR)	Total Metals Reduc. ³ (%TR)	Total Hydrocarbons Reduc. ³ (%TR)
Rooftop Disconnect. ^{12, 14}	25 or 50 ¹⁰	0	25 or 50 ¹⁰	0	25	50	50	NA		
Sheet flow to Veg. Filter 1	25 or 50 ¹⁰	0	25 or 50 ¹⁰	0	25 or 50 ¹⁰	50 or 75 ¹⁰	50 or 75 ¹⁰	20*		
Sheet flow to Veg. Filter and Conserv. Open Space 2 ¹²	50 or 75 ¹⁰	0	50 or 75 ¹⁰	0	50 or 75 ¹⁰	60 or 85 ¹⁰	60 or 85 ¹⁰	20*		
Grass Channel	10 or 20 ¹⁰	15	23	20	28	30	35	0	70 ⁷	62
Soil Compost Amendments	Can be used to decrease runoff coefficient for turf cover at a site. See design specs for Rooftop Disconnect., Sheet Flow to Veg. Filter, and Grass Channel					0	50	NA		
Vegetated Roof 1	45	0	45	0	45	50	70	NA		
Vegetated Roof 2	60	0	60	0	60	50	80	NA		
Rainwater Harvesting	90 ^{11, 12}	0	90 ^{11, 12}	0	90 ^{11, 12}	0	90 ¹¹	NA		
Permeable Pavement 1	45	25	59	25	59	65	80	NA	99 ⁹	
Permeable Pavement 2	75	25	81	25	81	65	90	NA	99 ⁹	
Infiltration 1	50	25	63	15	57	50	75	40*	99 ⁹	NA
Infiltration 2	90	25	93	15	92	50	95	40*	99 ⁹	NA
Bioretention 1	40	25	55	40	64	50	70	40*		62+
Bioretention 2	80	50	90	60	90	75	95	40*		62+
Urban Bioretention	40	25	55	40	64	50	70	40*		62+
Dry Swale 1	40	20	52	25	55	40	65	0 ⁵	70 ⁷	
Dry Swale 2	60	40	76	35	74	70	90	25*	70 ⁷	
Wet Swale 1	0	20	20	25	25	40	40	0		
Wet Swale 2	0	40	40	35	35	70	70	0		
Filtering Practice 1	0	60	60	30	30	60	60	35 ⁵	69 ⁷	84
Filtering Practice 2	0	65	65	45	45	85	85	70 ⁶	69 ⁷	84
Constructed Wetland 1	0	50	50	25	25	50	50	80 ⁷	42 ⁷	85
Constructed Wetland 2	0	75	75	55	55	80	80	80	42 ⁷	85
Wet Pond 1	0	50 (45 ¹³) 75 (65 ¹³)	50 (45 ¹³) 75 (65 ¹³)	30 (20 ¹³) 40 (30 ¹³)	30 (20 ¹³) 40 (30 ¹³)	50	50	70 ⁷	62 ⁷	81
Wet Pond 2	0	75 (65 ¹³)	75 (65 ¹³)	40 (30 ¹³)	40 (30 ¹³)	80	80	70	62 ⁷	81
Ext. Detention Pond 1	0	15	15	10	10	50	50	30 ⁵		
Ext. Detention Pond 2	15	15	31	10	24	70	75	60 ⁶		

¹ Based upon 1 inch of rainfall – 90% storm, Annual average runoff reduction as reported in CWP (2008b)

² Change in stormwater event mean concentration (EMC) as it flows through the practice and is subjected to treatment processes, as reported in CWP (2008b)

³ Total removal (TR) = product of RR and PR

⁴ Bacteria removal rates, as reported by Schueler et al (2007). An asterisk denotes where monitoring data is limited and estimates should be considered extremely provisional. NA indicates the practice is not designed for bacterial removal or is located far up in the treatment pathway, such that bacteria source areas are largely absent (e.g. green roofs and cisterns).

⁵ Median value from International BMP database.

- ⁶ Q3 value from International BMP database.
- ⁷ Median value from the National Pollutant Removal Performance Database (NPRPD, managed by the Center for Watershed Protection)
- ⁸ Average of zinc and copper, but only zinc for infiltration.
- ⁹ Based on fewer than five data points (i.e., independent monitoring studies).
- ¹⁰ The lower rate is for Hydrologic Soil Group (HSG) class C and D soils; the higher rate is for HSG class A and B soils
- ¹¹ Credit up to 90% is possible if all water from storms 1 inch or less is used through demand, and the tank is sized such that no overflow occurs. Total credit is not to exceed 90% as an isolated practice.
- ¹² See BMP design specification for an explanation of how additional pollutant removal can be achieved.
- ¹³ Lower nutrient removals in parentheses apply to wet ponds in coastal plain terrain.
- ¹⁴ The removal can be increased to 50% for HSG C and D soils by adding soil compost amendments, and may be higher yet if combined with secondary runoff reduction practices.

Source: Adapted from CWP (2008b) and Volume II of the Northern Marianas/Guam Stormwater Management Manual (2006)

8.4.6 Community and Environmental Factors (Table 8.9 below)

Do the remaining BMPs have any important community or environmental benefits or drawbacks that might influence the selection process? In this last step, **Table 8.9** is used to assess the following community and environmental considerations involved in BMP selection:

Maintenance. This column assesses the relative effort needed to maintain the BMP, in terms of three criteria: (1) frequency of scheduled maintenance, (2) chronic maintenance problems (such as clogging), and (3) reported failure rates. It should be noted that the regulations require routine BMP inspection and maintenance under certain circumstances, for which Virginia requires a long-term Maintenance Agreement between the BMP owner and the local jurisdiction within which the BMP is located. This provides legal assurance that routine maintenance will be done to assure the continued proper functioning of the BMP.

Overall Affordability. The BMPs are ranked according to (1) their relative construction cost per impervious acre treated and (2) their long-term maintenance costs. These costs exclude design, land acquisition, and other costs.

Community acceptance. This column assesses community acceptance, as measured by three factors: (1) market and preference surveys, (2) reported nuisance problems, and (3) visual orientation (i.e., is it prominently located or is it in a discrete underground or other out-of-sight location). It should be noted that a low rank can often be improved by a better landscaping plan.

Safety. This column provides a comparative index that expresses the relative public safety of a BMP. An open circle indicates a reasonably safe BMP, while a darkened circle indicates that deep pools may present potential public safety risks. The safety factor is included at this stage of the screening process because liability and safety are of paramount concern in many residential settings. It should be noted that a low rank can be improved by using measures that restrict access, such as fencing. However, such measures may affect the ranking related to aesthetics.

Habitat. BMPs are evaluated on their ability to provide wildlife or wetland habitat, assuming that an effort is made to landscape them appropriately. Objective criteria include size, water features, wetland features, and vegetative cover of the BMP and its buffer.

Aesthetic, Recreational Benefits or Other Concerns. BMPs are evaluated on their ability to (1) provide a perceived positive influence on the visual appearance of the lot or development, (2) contribute to the recreational value at the lot, development or community scale, ideally as part of a community greenway network, or (3) provide other perceived ancillary benefits.

Table 8.9. BMP Selection Matrix 6 – Community and Environmental Factors

BMP Group	Specific BMP	Ease of Maintenance	Overall Affordability	Community Acceptance	Safety	Habitat	Aesthetics and Other Concerns
Runoff Volume Reduction	Vegetated Roof	◐	◐	◐	○	●	Invasive veg. and water leaks; reg. inspection and maint. can address these
	Rooftop Disconnect.	○ to ◐	○ to ◐	◐	○	●	Impediments to use in existing local health and building codes
	Rainwater Harvesting	●	◐	◐	○	●	
	Soil Compost Amendments	○	○	○	○	○	Helps prevent standing water and adds soil moisture for plant materials
	Sheet flow to Veg. Filter and Conserv. Open Space	○	○	○	○	○	Inc. into landscape; overgrown vegetation
Swales & Open Channels	Grass Channels	○	○	○	○	●	Attractive natural drainage mechanism
	Dry Swales	○	◐	○	○	●	Attractive natural drainage mechanism with enhanced infiltration and treatment
Filtering Systems	Filtering Practices	●	●	○	○	●	Filter media replacement; Underground practices are not seen and therefore often not maintained
	Bioretention 1	◐	◐	◐	○	◐	Inc. into landscape; mosquitoes; overgrown vegetation
Infiltration Practices	Permeable Pavement	●	◐	◐	○	●	Susceptible to failure if poorly installed or maintained
	Infiltration	●	◐	○	○	●	Susceptible to failure if poorly installed or maintained
	Bioretention 2	◐	◐	◐	○	◐	Inc. into Landscape; Mosquitoes; Overgrown vegetation

BMP Group	Specific BMP	Ease of Maintenance	Overall Affordability	Community Acceptance	Safety	Habitat	Aesthetics and Other Concerns
Basins	Constructed Wetlands	◐	◐	◐	◐	○	Undesirable animals; Mosquitoes; Overgrown vegetation and unsightly conditions
	Wet Swales	○	●	◐	○	◐	Undesirable animals; Mosquitoes; Overgrown vegetation and unsightly conditions
	Wet Ponds	○	○	◐	●	○	Geese, Odors, Mosquitoes, Floatable Trash; Safety & liability concerns
	Extended Detention 1	○	○	◐	●	●	Undesirable animals; Overgrown vegetation and unsightly conditions
Mfr Treatment Devices	Hydrodynamic Devices	◐	●	○	○	●	Underground practices are not seen and therefore often not maintained
	Filtration Devices	●	●	○	○	●	Underground practices are not seen and therefore often not maintained
	Storage Devices	◐	●	○	○	●	Underground practices are not seen and therefore often not maintained
○ High or Good or Easy ◐ Medium ● Low or Difficult							

8.4.7 Consideration of Regulatory Restrictions and Setbacks (Table 8.10 below)

Table 8.10 presents an overview of ten site-specific considerations of environmental resources or infrastructure present on the site or Virginia rules or conditions that may apply that will influence where a BMP can be located on the site (i.e., setback or similar restriction).

Table 8.10. Location-Specific Restrictions and Setbacks

Factor	Considerations
<p>Jurisdictional Wetland</p> <p>U.S. Army Corps of Engineers(USACE) Section 404 Permit</p> <p>and/or</p> <p>Va. Department of Environmental Quality (DEQ) Section 401 Water Quality Certification and Wetlands and Water Protection Permits</p>	<ul style="list-style-type: none"> Wetlands should be delineated prior to siting BMPs Demonstrated that the impact to a wetland complies with all of the following principles in descending order of priority: (1) avoid direct or indirect impacts; (2) minimize impact by limiting the degree or magnitude of activity; and (3) mitigate unavoidable impacts through wetland restoration or creation, providing justification that no practical upland treatment alternatives exist. Always check with local, state and federal jurisdictions for applicable regulations. Using natural wetlands for stormwater treatment is strongly discouraged, unless they are severely impaired and construction would enhance or restore wetland functions; impacts to natural wetlands will require state and federal permits. Direct pipe outfalls to natural wetlands should be restricted; stormwater must be treated prior to discharge into a natural wetland and, where practical, excess stormwater flows should be conveyed away from jurisdictional wetlands. BMPs are restricted from location within the Chesapeake Bay Preservation Act RPA buffer. RPA buffers may be used as a non-structural filter strip accepting sheet flow, not concentrated flows.
<p>Stream Channel</p> <p>USACE Section 404 Permit</p> <p>and/or</p> <p>Va. DEQ Section 401 Water Quality Certification and Wetlands and Water Protection Permits</p>	<ul style="list-style-type: none"> All waterways (including streams, ponds, lakes, etc.) should be delineated prior to design. Use of any Waters of the U.S. for stormwater quality treatment is contrary to the goals of the Clean Water Act and should be avoided. BMPs should not be placed on-line (in-stream) under most conditions and will require federal and state permits, if necessary, providing justification that no practical upland treatment alternatives exist. If an on-line pond is necessary, its use for channel protection or flood protections purposes are preferred to use for water quality treatment. Implement measures that reduce downstream warming. Activities such as excavation, shore protection, structures, dams, and water level controls are regulated. State (DEQ) water quality standards apply and may not be violated.
<p>Shoreland Management, Chesapeake Bay Preservation Areas, and Stream Buffers</p> <p>Va. Marine Resource Commission (VMRC)</p> <p>and/or</p> <p>Applicable shoreland development ordinances</p>	<ul style="list-style-type: none"> VMRC regulates tidal wetlands (elevations below 1.5 x the mean high tide elevation), associated shorelands, and all state bottoms (the land beneath streams, rivers, etc. that comprise state waters). All Tidewater Virginia local governments (§ 62.1-44.15:67 et seq., Code of Virginia) have Chesapeake Bay Preservation Area ordinances that require buffers and setbacks from shorelines; other localities outside Tidewater Virginia may also have shoreland development ordinances with similar requirements. Consider how stormwater outfall channels will cross a buffer to reach a stream.

Factor	Considerations
100-Year Floodplain Va. Department of Conservation and Recreation (DCR) Division of Dam Safety and Floodplain Management and Applicable local floodplain management ordinances and stormwater review authority	<ul style="list-style-type: none"> Grading and fill for BMP construction is strongly discouraged within the ultimate 100-year floodplain, as delineated on FEMA flood insurance rate maps, FEMA flood boundary and floodway (or more stringent local) maps. Floodway fill may not raise the 100-year water surface elevation by more than 0.5 feet (local regulations may be more stringent).
Water Wells Local health authority	<ul style="list-style-type: none"> Observe local wellhead protection zones and minimum setbacks. Consult the Virginia Department of Health, the local health department, and the local water utility. A 100-foot setback for infiltration practices and 50-foot setback for other BMPs is recommended. There should be no infiltration of confirmed hotspot runoff; runoff from potential hotspot runoff should be restricted and have suitable pre-treatment.
Utilities Local review authority	<ul style="list-style-type: none"> Contact “Miss Utility” to locate existing utilities prior to design. Note the location of proposed utilities to serve development. BMPs are discouraged within utility easements or rights-of-way for public or private utilities.
Septic Drain Fields Local health authority	<ul style="list-style-type: none"> Consult the local health authority. A minimum 50-foot setback from a drainfield edge is recommended for BMP location.
Roads Virginia Department of Transportation (VDOT) and/or Local transportation authority or DPW	<ul style="list-style-type: none"> Consult the local transportation authority, DPW or subdivision ordinance/regulations for setback requirements from local roads and streets. Consult VDOT for setbacks from state-maintained roads. Approval must also be obtained for any stormwater discharges to a local or state-owned storm drain or conveyance channel.
Structures Local review authority	<ul style="list-style-type: none"> Consult the local review authority for any BMP setback from structures.

Factor	Considerations
<p>Karst (Sinkholes)</p> <p>Local review authority EPA Region III UIC Pgm Virginia Cave Board</p>	<ul style="list-style-type: none"> • Geotechnical testing is recommended and may be required within karst areas. • Existing sinkholes should be identified and delineated on site plans. • BMPs should be designed to be off-line to limit volumes and flow rates managed by individual practices; infiltration or pooling of stormwater near sinkholes is discouraged; sinkhole formation is less likely when practices such as bioretention and vegetated filters are used; sinkholes should be remediated and stormwater directed away from these areas during and after construction. • Any discharge of stormwater runoff to a sinkhole or other karst feature must meet the water quality control criteria set out in 4 VAC 50-60-63 and the water quantity control criteria set out in 4 VAC 50-60-66 of the Virginia Stormwater Management Regulations • Formation of sinkholes within an BMP is evidence of failure; sinkholes occurring within BMPs should be repaired as soon as feasible after the first observation, using appropriate engineering techniques (e.g., VDOT IIM228 – <i>Sinkholes: Guidelines for the Discharge of Stormwater at Sinkholes</i>; WVDEP, 2004; MDE, 2000; etc.). • Consistent with federal environmental regulations at 40 CFR parts 144-148, some karst features receiving runoff may be considered to be class V injection wells and must be registered as such with the EPA Region III. To ensure compliance in cases where stormwater runoff is discharged to a karst feature, DEQ recommends coordination with the EPA Groundwater & Enforcement Branch (3WP22), U.S. EPA Region 3, 1650 Arch Street, Philadelphia, PA 19103 (Phone: 215-814-5427; FAX: 215-814-2318).

8.4.8 Spatial Scale At Which Practices Are Applied (8.11 below)

The matrix provided in **Table 8.11** below compares the different spatial scales at which the various stormwater control measures can be applied to reduce runoff and remove pollution. The major change in the new BMP design specifications is that most practices are applied at a smaller spatial scale than has been done in the past. This means that more practices will be needed at each site. Note that the area ranges specified in **Table 8.11** for contributing drainage areas (CDAs) are approximate, and may actually be greater or smaller depending on the specific design and site characteristics. Multiple BMPs of the same or different kind may be used in combination to treat a larger CDA.

Table 8.11. Comparison of Practices Based on Contributing Drainage Area Served

Practice	Spec No.	Space ¹	Micro Scale	Small Scale	Normal Scale	Moderate Scale	Large Scale
Rooftop Disconnection	1	Nominal	250 to 1000 sq. ft.				
Sheet Flow to Veg. Filter or Conserved Open Space	2	15-25%		1000 to 5000 sq. ft.	5000 to 25,000 sq. ft.		
Grass Channels	3	5-15%			20,000 sf to 250,000 sq. ft.		
Soil Compost Amendments	4	Nominal	250 sq. ft. to 2 acres				
Vegetated Roofs	5	Nominal	Residential 250 to 2000 sq. ft.	Commercial 2,000 to 200,000 sq. ft.			
Rainwater Harvesting	6	Nominal					
Permeable Pavement	7	Nominal	250 to 1000 sq. ft.	1000 to 10,000 sq. ft.	10,000 to 200,000 sq. ft.		
Infiltration	8	1-4%	250 to 2500 sq. ft.	2500 to 20,000 sq. ft.	20,000 to 100,000 sq. ft.		
Bioretention	9	3-5%	250 to 2500 sq. ft.	2500 to 20,000 sq. ft.	20,000 to 100,000 sq. ft.		
Urban Bioretention	9A	Nominal	250 to 2500 sq. ft.	2500 to 20,000 sq. ft.			
Dry Swales	10	5-15%			20,000 to 250,000 sq. ft.		
Wet Swales	11	5-15%			20,000 to 250,000 sq. ft.		
Filtering Practices	12	0-3%			20,000 to 250,000 sq. ft.		
Constructed Wetlands	13	3%					10 + acres, unless favorable water balance
Wet Ponds	14	1-3%					
Extended Detention Ponds	15	1-3%					

¹ Typical footprint of BMPs as a percent of the total site area

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